Abstract

Title of Thesis: Preliminary Stock Assessment of the Chesapeake Bay Blue Crab Population

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A preliminary stock assessment using data from a commercial fishery survey was completed. The maximum average attainable size (L_{inf}) was found to be 174.25 mm (6.9 in) for males, and 171.7 mm (6.8 in) for females. The von Bertalanffy growth coefficient (K) was determined to be 0.83 for males and 0.57 for females. Yield-per-recruit analysis indicated that a significant amount of yield-per-recruit is lost if males are fished before reaching approximately 145 mm (5.7 inches). Results for females show that the size at first capture should be approximately 124 mm (5 inches), after which the yield-per-recruit gained by waiting is minimal. The nature of the recruitment-stock relationship could not be characterized in this study; however, results indicate that a relationship does exist. A comparison of early and late season catch curves indicated surplus production of biomass in the 1987 pot fishery. The potential use of change in sex ratios estimators for stock assessment is discussed.

Preliminary Stock Assessment of the

Chesapeake Bay Blue Crab Population

by
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INTRODUCTION

The blue crab is currently the most important commercially and recreationally fished species in the Chesapeake Bay; the annual catch in 1986 was 90 million pounds, worth an estimated 31 million dollars (Cronin, 1987). In spite of its importance, little is known about the effects of the fishery on the blue crab population; many of the basic data required for a blue crab stock assessment are unreliable (Jones et. al, 1983; Stagg, 1986). The importance of the fishery, and the dependence on it, necessitate the timely completion of a stock assessment. In accordance with this need, the goal of this research is to produce a stock assessment of the Chesapeake Bay blue crab population using the data which are currently available.

A description of the blue crab life history is presented in Chapter 1, along with a discussion of the fishery, including gear types, regulations, and historical trends. Chapter 2 focuses on stock assessment, and includes yield-per-recruit analyses, a discussion of the recruitment-stock relationship, and an analysis of production in the fishery. Chapter 3 deals with population sex ratio, and the potentially powerful uses of basic sex ratio information. Finally, the results of this research are utilized to formulate recommendations for future management of the Chesapeake Bay blue crab population.

Chapter 1.

Blue crab life history and fishery

1.1 Life History

Recent research has done little to expand upon the blue crab life history pattern described in the 1950's (Van Engel, 1958). However, concise knowledge of the life history is vitally important; Cronin (1987) emphasizes: "effective management must be based on the best possible knowledge of the life history and requirements of the species." Crabs exist in a multi-dimensional environment which has a well-documented impact on the life history; however, because the environment is dynamic (and therefore difficult to measure), it is virtually impossible to definitively characterize the life history. The description can only be made for a "typical" crab in an "average" year--it can be said that "most" crabs grow at a specific rate, spawn in a certain location, live a certain number of years, etc.

The blue crab, Callinectes sapidus Rathbun (phylum Arthropoda, class Crustacea, order Decapoda, family Portunidae) (Millikin and Williams, 1984), ranges from Cape Cod to Uraguay, and has been reportedly been found north to Massachusetts Bay. Typically, the blue crab can be found offshore to at least 36 meters (120 ft), but it is especially common in estuaries, where it ranges into fresh water (Gosner, 1978).

The conventional wisdom regarding the typical life history for Chesapeake Bay blue crabs indicates that the blue crab utilizes the entire estuary during its short-lived existence (Lippson, 1971); the preferred areas within the estuary for both juveniles and adults are those which are vegetated--most probably due to increased food availablility, and decreased predator efficiency in such regions (Orth, 1987). Blue crabs are particularly susceptible to predation by numerous fish species and other blue crabs during molting, and following molting, while still in the soft shell stage. The life cycle, as it is currently understood, begins with the May through October hatching of larval crabs from the sponge of fertilized eggs carried by an adult female. Laboratory studies have shown that spawning will occur at temperatures ranging from 19-29^{o}C and salinities ranging from 23-32.6 parts-per-thousand (ppt), however, optimum spawning temperatures were found to range from 21.6-22.8^{o}C (Costlow and Bookhout, 1959; Jones et. al., 1983). As a general rule, based on the distribution of zoeae, spawning is thought to occur in Virginia waters, and be concentrated at the mouth of Chesapeake Bay, in the channel region between Cape Henry and Cape Charles (Jones et. al., 1983); however, a substantial amount of spawning may also occur outside the mouth of the Bay (Van Engel, 1958). Cronin (1987) defines different spawning regions depending on the amount of rainfall in a year: "in wet years, when salinity is low in most of the Bay, crabs hatch in waters inside and outside of Cape Henry and Cape Charles at the mouth of the Bay. The area is larger in years of average salinity. In dry, salty years, sponge crabs can hatch their larvae as far up as the mouth of the Rappahannock." Thus, the location of spawning is dependent upon the physical space which provides the required salinity conditions, and can vary according to annual rainfall.

The newly hatched larval crab, termed a zoea, immediately swims away and assumes a planktonic existence (Lippson, 1971). The zoeae rapidly undergo a series of molts, and during each of the successive molts, the legs and pleopods become more fully developed (figure 1.1) (Lippson, 1971). This transformation requires about 30 days, and 7-8 molts. Early zoeal stages of the blue crab are positively phototrophic, and hence, they are concentrated in the high salinity surface waters (usually 20 ppt or greater) at the mouth of Chesapeake Bay; the effect of this surface concentration is that zoea are susceptible to predation and subject to meteorological conditions (Costlow et. al., 1959; Tagatz, 1968a; Dudley and Judy, 1971; Sandifer, 1973; Dittel and Epifanio, 1982; Perry, 1975). Later larval stages are most abundant in waters approximately 30-40 miles Southwest to East of the mouth of Chesapeake Bay. These surface waters have a net flow toward the ocean, greatly influenced by the wind, which carries most of the fresh water flow (and hence, the larvae) to the ocean. After molting a total of 7 to 8 times in a period of 30 - 60 days (depending on temperature and salinity), larvae transform into the megalops stage at about 2.5 mm carapace width (Costlow and Bookhout, 1959). The megalops is more crab-like than the zoea--it has five recognizable pairs of legs, with the first pair modified as claws (figure 1.1). Megalopae are reputed to be most abundant from late July to mid-September in coastal shelf waters respectively (Lippson, 1971). Following larval development, early stage true crabs migrate up the Bay to lower salinity and shallow waters during summer months (as early as July); later they move to slightly deeper channels to hibernate during colder months. Typically, at least some juveniles do not migrate north of the Potomac River mouth before overwintering. During the next spring and summer, these juveniles continue their Northern migration, concentrating in nursery areas in the mid-portion of the Bay (Van Engel, 1958). The juvenile crabs, at first, molt every few days. As they increase in size, the time interval between molts also increases (Lippson, 1971). Growth of blue crabs is believed to be dependent on temperature, molt frequency, food availability and nutritional quality, and life stage. Growth primarily occurs during molting, although small weight increases occur through relative changes in tissue content during the intermolt period (Millikin and Williams, 1984). A general rule of thumb is that a crab grows about 1/3 in width and length and doubles its volume with each molt. According to Van Engel et. al. (1973), growth occurs in Chesapeake Bay blue crabs from late April to mid-October, when temperatures are generally above 15^{o}C.

Crabs enter a state of semi-hibernation during winter in the Chesapeake Bay, and during this time, they rarely feed, move any great distance, or molt.(Van Engel, 1958). The precise timing of dormancy is dependent upon temperature; however it usually lasts from November until March. With warming spring temperatures, growth and movement resumes. Crabs are generally believed to reach maturity in their second summer with the peak in late August and September. Males may mature earlier than females, but this is not known with certainty. Females molt eighteen to twenty times before becoming sexually mature, at which time growth ceases. Males probably become sexually mature at the eighteenth or nineteenth molt, but may continue to grow and molt an additional three to four times thereafter (Van Engel, 1958). Each male can mate with several females; however, females can mate only once, when they are soft for the last time, changing from the juvenile stage (triangular apron) to the adult stage (semi-round apron). Male blue crabs appear to prefer lower salinity waters than do females; maximum concentrations of males occur in salinities of 3-18 ppt while females are concentrated in waters with salinities greater than 10 ppt. Most mating occurs in the mid-Bay region where these salinity preferences overlap (Lippson 1973, Shea et. al., 1980). Mating results in the placement of sperm "packets" in the female which will be used during the following summer. After mating, the males remain in the upper Bay and tributaries, where some will mate again. Adult females migrate relatively quickly down the Bay and tributaries; many reach the lower Bay by mid-November and there begin their winter dormancy. Van Engel (1958) reports two major migrations of mature females toward the spawning grounds in the lower Bay, one during October and November, and a second migration during the following May. The May run is composed, in part, of recently mated females, but predominantly of mature females that overwintered before reaching spawning regions in the lower Bay the previous fall. With the resumption of activity in the spring, adult females utilize the sperm received the previous year and produce an orange-colored egg mass, or "sponge" (attached to the fringes of the hairs on the pleopods) (Lippson, 1971), which turns to yellow and then to brown as the larvae develop. Females produce 0.5-2 million eggs per sponge (Lippson, 1971). Eggs are carried approximately 2 weeks before hatching; the exact length of time is influenced by temperature, salinity, and other environmental factors (Lippson, 1971). Females spawn from May to October in the lower Bay where the salinity is sufficiently high (25 - 30 ppt) to allow development of the eggs and larvae (Lippson, 1971). Spawning of blue crabs is initiated progressively earlier in the spring at lower latitudes. Approximately 98% of the females are capable of spawning two or more times throughout their lives (Hard, 1942, Lippson et. al., 1979, Van Engel, 1958, Pearson, 1948). Some, but not all, females spawn a second time. Crabs are thought to live about 2 to 3 years, dying in their second winter if uncaught, or not preyed upon. This is obviously a comparatively short life expectancy in terms of commercially harvested Bay species.

1.2 The Blue Crab Fishery

1.2.1 Gear

There are numerous crabbing gears used in the Chesapeake Bay, which correspond to the multiple fisheries which exist. Currently, the prominent gears are pots, trotlines, crab dredges, and crab scrapes. In the early years of the Chesapeake Bay fishery, trotlines were the principal gear used for catching hard blue crabs, but eventually the crab pot (patented by Lewis, a Virginian, in 1938) became the chief gear for hard blue crabs except during winter (Cronin, 1987; Van Engel, 1962). Pots and trotlines are fished in the spring, summer, and fall months to harvest male and female hard crabs, and to a lesser extent peelers and soft crabs; dredges are used in the winter months to catch mature females overwintering in Virginia waters of the Bay and scrapes are used to fish for peelers and soft crabs (Tang, 1983; Warner, 1976).

Typical Chesapeake Bay crab pots are commonly 0.6 m (2 ft) square, top and bottom, and 53.3 cm (21 in.) high, made of galvanized or plastic coated 18 gauge steel wire of 3.8-5.0 cm (1.5-2.0 in) mesh specially treated with zinc to retard rust (figure 1.2)(Cronin, 1987; Warner, 1976). Crab pots consist of two to four conical funnels serving as entry ports, a partition separating the "upper" and "lower" section, which utilizes a blue crab crab's tendency to swim up and away from the bottom if alarmed, and a cylindrical bait "box" (typically baited with menhaden, or alewives) in the center of the lower section (Cronin, 1987; Warner, 1976). Crab pots are set about 30.5 m (100 ft) apart at the edges of river or bay channels of Chesapeake Bay in depths of 1.8 to 18 m (6 to 60 ft), with actual fishing time averaging 2.5 h/100 pots (Cronin, 1987; Van Engel, 1962).

Trotlines originated about 100 years ago, and their construction has improved noticeably over the years (Cronin, 1987). Today's trotlines are constructed of plain cotton twine 0.4 to 1.6 km (0.25 to 1 mi.) long with baits (eel, fish, bull lips, or chicken parts) tied intermittently to the line (figure 1.2). Heavy metal objects, such as engine blocks, are used as anchors at each end, attached to 1.2 to 1.5 m (4 or 5 ft) of chain, a rope pennant, and several plastic (bleach) bottles serving as marker buoys (Cronin, 1987; Warner, 1976). This is a shallow water gear, set in water depths of 1.5 to 4.5 m (5 to 15 ft).

Scrapes are employed only in grassy areas with depths of 0.7-5.0 m (2-15 ft). A crab scrape operates more by catching eelgrass (Zostera marina) than by catching crabs--its heavier bottom bar crops the plants, without pulling up the roots, because it is rounded, and has no teeth (figure 1.2). Scrapes are a gear which target soft-shell, and peeler crabs, which have gone into the grass to molt, and, to a lesser extent, male hard crabs, which enter the grass searching for females undergoing their terminal molt (Warner, 1976). The principal scraping areas are around the grassy islands and shores near the center of the Bay. The eastern shore of the Bay, specifically Tangier and Pocomoke Sounds lead the world in production of soft crabs. The peeler fishery has several gears according to Cronin (1987), of which scrapes and peeler pots are the most widely used. With peeler pots, adult males are placed in the bait boxes of modified pots because peeler females about to shed to maturity and mating are attracted to them.

An important change has been made in the handling of peeler crabs. The overboard floats, used for 100 or more years, are rarely used commercially any longer because they are subject to weather, predation, and other sources of mortality. Now, most crabs are shed in troughs under cover, with water pumped over them. This substantially reduces mortality due to environmental conditions and predation, in addition to providing access for the frequent removal of soft crabs 24 hours a day (Cronin, 1987).

The primary gear in the Virginia winter fishery is the crab dredge, a heavy, rectangular frame, bearing a 1.8 m (6 ft) toothed drag bar on its lower edge, followed by a mesh bag made of rings, cotton and twine (figure 1.2) (Van Engel, 1962).

Recreational crabbing typically consists of using handlines or crab pots. Handlines are an important recreational gear--they may be used virtually anywhere--off piers, bridges, or boats. They are employed widely, but only for recreational crabbing (Cronin, 1987). Crab pots may be used in limited numbers by shoreline property owners for recreational crabbing. Short trotlines, less than 500 feet in length may also be laid by recreational crabbers.

1.2.2 Regulations

The blue crab fishery is collectively regulated by MDNR, VMRC, and PRFC; these agencies determine the laws on seasons, locations, gear types, and size limits. As a result of the multiple management agencies, size limits and gear regulations vary among Maryland, Virginia, and the Potomac river (table 1.1, figure 1.3); these existing regulations originated in economic considerations, conservation concerns, responses to new crabbing methods, and the traditions of each state's tidewater areas (Cronin, 1987).

1.2.3 Historical Trends

Historical commercial blue crab catch and effort statistics for Chesapeake Bay were first collected in 1880 as part of a nationwide assessment of the fishing industry. Based on those statistics, the reported catch for the Maryland-Virginia fishery in that year was about 4 million pounds (Tang, 1983). Since then, because of the improved efficiency of fishing gears, increasing intensity of fishing, and increasing consumer demand, landings have increased dramatically, reaching a historical peak in 1966 when 97 million pounds were landed (Tang, 1983).

Historical catch data indicate that during the last 100 years, fluctuations in annual catches of blue crabs have been commonplace (Tang, 1983) (figure 1.4). Cronin (1987) reveals that very few measures of the real, or even relative, abundance of crabs in the Chesapeake Bay at any stage in their life history are available. The existing data are not good enough to measure long-term changes, but do show that the number of crabs harvested has always varied, sometimes widely, from year to year. For several periods, as in the mid-1960's, high catches occurred year after year, whereas other periods provided smaller populations and catches. Such a range of high and low years has probably always existed, and will continue for natural reasons. Unfortunately for fishery managers, the effects of harvesting are added on top of these natural fluctuations.

A problem with historical catch data is that it represents the fraction of the total commercial harvest which is sold to dealers and does not include catches sold in the basket trade or landings in the recreational fishery--both of which could be substantial (Jones et.al., 1983).

Estimates of the commercial catch in Virginia waters have been determined from dockside sales receipts throughout the history of the fishery. These receipts were summed over the fishing season to give the total annual catch by gear type. Total effort was based on the maximum amount of gear that could be legally deployed per license (Jones et. al., 1983). Data collection procedures in Maryland for the commercial fishery were very similar to those used in Virginia until 1981, with the exception of the crab pot fishery. From 1978-1980, pot catch and effort was determined from daily records of catch and effort reported by commercial watermen. Since 1981, statistics in Maryland have been based on a MDNR random survey sampling program which is described in Summers, Hoffman, and Richkus (1981) (Jones et. al., 1983).

Commercial blue crab catches in Chesapeake Bay are marketed in three basic categories--hard crabs, soft crabs, and peelers.

Total annual landings in the Maryland-Virginia hard crab fishery are variable interannually; in general, catches increased from 1929 through the early 1960's, declined through 1979, and then increased substantially thereafter (Jones et.al., 1983). Some believe that the dramatic increase seen in 1981 was due to the different reporting system instituted at that time; however, Rothschild et.al. (1988) indicate that an increase in abundance or availability did, in fact, occur. A preliminary analysis of MDNR fishery independent trawl data collected from 1977 through 1986 revealed a trend in increasing abundance beginning in 1981 coinciding with MDNR's reported catch statistics, which show a sudden increase in 1981. It seems that this marked increase actually reflects an increasing availability of blue crabs at that time (Rothschild et. al., 1988)

Chesapeake Bay hard crab catches in the trotline fishery decreased significantly from the 1930's to the 1980's (figure 1.5). Throughout most of this period, catches in the Maryland portion of the Bay exceeded those from Virginia waters.

Crab pot catches in Chesapeake Bay increased from the late 1930's (when the fishery first developed) through the mid-1960's when harvests peaked at about 57 million pounds (figure 1.6), and have generally decreased since that time. As was the case with trotlines, crab pot catches have increased substantially in Maryland since 1980.

Historically, soft crab and peeler catches peaked in the early 1900's at about 10 million pounds a year (figures 1.7, 1.8). Landings have gradually decreased since then to an annual level of about 2 million pounds a year during the decade of the 1970's (Tang, 1983).

Reported catches in the Virginia winter dredge fishery decreased from about 8 million pounds in the early 1930's to a historical low of approximately 2 million pounds in the early and mid-1940's (figure 1.9). Catches then increased through the early 1950's, decreased again in the late 1950's, and reached a historical peak in the mid-1960's.

Blue crab fishing effort, as presented in Fishery Statistics of the U.S. is the estimated maximum amount of gear fished at any one time during the crabbing season.

Statistics show that there has been a marked increase in the fishing intensity for hard crabs in the Bay since the 1960's. Crab pot effort has increased linearly from the beginning of the fishery in the late 1930's, reaching an historical peak in 1977 (figure 1.10). Currently, Cronin (1987) roughly estimates that 265,000 crab pots may be in use in Maryland and 400,000 in Virginia. Trotline effort remained relatively constant from 1929 to 1969 and increased rapidly in each year from 1969 through the late 1970's. In both the scrape and dredge fishery, effort increased from 1929 through the late 1930's, decreased during World War II, increased again through the late 1950's and declined relatively thereafter (figure 1.10) (Tang, 1983).

Recreational crabbing has been only partially surveyed, so accurate summaries of the quantity and expenditures of catch and effort are not possible, according to Cronin (1987).

According to Jones et. al. (1983), the status of blue crab stocks in Chesapeake Bay will continue to be difficult to assess until the programs used to collect catch and effort statistics in Maryland and Virginia are modified. At the present time, these programs provide, at best, only the crudest measures of catch and effort in the commercial fishery and do not address landings in the recreational fishery. They therefore conclude that because of the quality of the existing estimates of catch and effort, it cannot be determined with any degree of certainty, whether stocks have increased, remained constant, or decreased in recent years.

Chapter 2.
Stock Assessment

2.1 INTRODUCTION

Stock assessments are evaluations of the effect of fishing on the current status of a fishery and the outlook for the future (Sissenwine, 1981); the objective of stock assessments is to provide the information necessary for the formulation of management plans which will attempt to maximize the production from a population while simultaneously ensuring that the population is exploited in a manner which allows continued production in the future. Stock assessments generally include discussions of yield-per-recruit, the relationship between stock and recruitment, and production estimates of the species studied.

2.1.1 Yield-Per-Recruit

The goal of any commercial fishery is to obtain as much revenue, in the form of yield, as is possible for a given expenditure in fishing. Yield-per-recruit modeling is used to determine the yield-per-recruit at different levels of fishing mortality and sizes of entry into the fishery, thus providing information on the combination of fishing mortality and age-at-first-capture which produces the largest yield-per-recruit (Beverton and Holt, 1957; Ricker, 1975). This information provides a basis on which specific regulations pertaining to fishing mortality rate, and age (size) at first capture can be made.

The data required to assess yield-per-recruit include growth parameters (classically, the parameters of the von Bertalanffy growth equation, K, and L_{inf}) and estimations of fishing and natural mortality. In the Ricker (1975) approach to calculating yield-per-recruit, a table of age and weight distributions, with their corresponding instantaneous rates of growth, natural mortality, and fishing mortality is compiled (table 2.1). The computation of a yield-per-recruit table begins by listing the ages at capture, and their corresponding weights-at-age. The natural logarithm of the weight is determined, followed by finding the difference between this value, and the natural logarithm of the next weight-at-age (G). Natural mortality rates are assigned to each period between t and t+1 by multiplying the instantaneous natural mortality rate by the portion of time over which this mortality acted (M). Fishing mortality rates are similarly computed for each period, from t to t+1 (F). The difference G-F-M can then be found; e $(2.718)^{G-F-M}$ is determined, and termed the weight change factor. In order to obtain the weight of the stock at time t+1, the weight at time t is multiplied by the preceding weight change factor. The mean stock weight is then found by averaging the weight of the stock at times t and t+1. The mean stock weight for a time interval is then multiplied by the rate of fishing which occurred during that interval to obtain an estimate of yield-per-recruit. The yield-per-recruit for each age-at-capture is then summed to obtain the total yield-per-recruit.

The most commonly used yield-per-recruit models in fisheries management are the Beverton and Holt and Ricker methods (Beverton and Holt, 1957; Ricker, 1975). The Beverton and Holt method is based on the von Bertalanffy growth equation, and assumes that the instantaneous rate of fishing is constant over the life span after recruitment, and the instantaneous natural mortality is constant after the (hypothetical) age at which the fish would have been zero length if it had always grown according to the Brody-Bertalanffy relationship (figure 2.17). The Ricker method has two commonly used forms: (1) an exponential form which assumes that the biomass of the stock changes in an exponential manner during any interval when growth, natural mortality, and fishing rates are all constant; and (2) an arithmetic form which uses the arithmetic mean of the stock biomass at the start and end of any interval during which all three rates are constant as an estimate of the average biomass present during the interval (figure 2.1).

2.1.2 Recruitment-Stock Relationship

Recruitment stock theory predicts the number of recruits which will be produced by the population for any given stock size (Beverton and Holt, 1957; Ricker, 1954). The theory has two classic branches, which share a common prediction: at relatively low stock size, recruitment increases nearly in proportion to stock size. One branch, popularized by Ricker (1954), suggests that at relatively high stock sizes, recruitment will decline ($R= \alpha Se^{-Bs}$); the other branch, developed by Beverton and Holt (1957), suggests that at relatively high stock sizes, recruitment does not decline, but rather approaches an asymptotic value ($1/\alpha + B/S$) (figure 2.2). The curvilinearity of the traditional Ricker and Beverton and Holt recruitment stock curves is important because it serves as a stabilizing mechanism for the population--the number of recruits produced per spawning adult increases when the stock declines and decreases at high stock abundance (Rothschild, 1986).

2.1.3 Production

Production modeling is founded on the premise that a fish population produces more individuals on an annual basis than is necessary to maintain its average biomass through reproduction and growth (Schaefer, 1954; Fox, 1970; Pella and Tomlinson, 1969; Pitcher and Hart, 1982). The positive arithmetic difference between annual biomass and the biomass of the individuals necessary to keep the population in stable equilibrium is termed surplus production. Theoretically, a population can be maintained in equilibrium at a desired biomass by removing this surplus production each year through fishing. Accordingly, the objective of production models, which require data on biomass (abundance), yield, fishing effort, and the rate of growth of the biomass of the population, is to determine points where equilibrium yield can be sustained indefinitely.

Three of the most widely used production models are the Schaefer, Pella and Tomlinson, and Fox surplus production models. Each of these models is derived from the logistic surplus production model (figure 2.3). The logistic surplus production model assumes that the total biomass of a stock is determined by the carrying capacity of the ecosystem of which the stock is a part. Under equilibrium conditions, the instantaneous rate of natural growth of biomass (surplus production) is directly proportional to the biomass, and also to the difference between the theoretical maximum biomass and biomass, and is inversely proportional to the theoretical maximum biomass.

2.2. Yield-per-recruit

Reliable estimates of growth parameters for the Chesapeake Bay blue crab population are not available; however, completion of a yield-per-recruit analysis is contingent upon parameter estimates. Therefore, empirical data were utilized to formulate preliminary estimations of growth parameters, and mortality rate. The estimations of growth and mortality will be discussed, followed by a description of how these parameters were utilized in a yield-per-recruit analysis.

2.2.1 Growth

Growth parameters were estimated from empirical data, which required: (1) construction of age distributions; (2) formulation of growth curves; and (3) estimation of von Bertalanffy growth parameters.

On-board observations of 60 commercial crabbers' crabbing operations were made and approximately 66,000 crabs sampled in a 1987 pilot study conducted on the commercial blue crab fishery in Maryland:

	Number of Units Sampled	Number of Crabs	Number of Days
Pots	23,640	39,399	85
Scrapes	1,113	10,837	31
Trotlines	519	15,560	34

Crabs were sampled in the waters of Calvert, St. Mary's, Dorchester, Talbot, and Somerset counties (figure 2.4). The total number of crabs caught by each unit of nominal effort (per pot, per scrape run, per trotline run) was recorded along with carapace width, sex, and maturity condition on all crabs caught per unit of nominal effort on a regular basis (i.e. every third pot, every third scrape run, etc.) (figure 2.5).

(1) Construction of Age Distributions

For each sampling day (by gear) carapace width and sex data were tabulated, and adjusted for effort, to derive estimates of catch-per-unit-effort (CPUE). Data were effort-adjusted by summing the number of crabs in each size class (0 to 200 mm in 10 mm increments) and dividing this number by the amount of gear used that day. Thus, if 350 crabs in the 100-110 mm size class were captured on a sampling day where 500 pots were fished, then the average CPUE for the 100-110 mm size class would be 0.7 for that day. Average CPUE by 10 mm size class was used to construct daily effort-adjusted length (carapace width)-frequency histograms by sex (figure 2.6).

The daily, effort-adjusted histograms exhibited significant variability in the existence and location of modes. Composite histograms for the months of June, July, and August were constructed for each sex to smooth the data (tables 2.2, 2.3, 2.4) (figures 2.7, 2.8). Due to the problem of the selectivity of commercial crabbing gear (scrapes select for small crabs, pots select for larger crabs), average CPUE by size class for pots and scrapes was combined to obtain a complete size distribution.

Several modes are evident in the monthly length-frequency distributions (figures 2.7, 2.8) (table 2.5). The modes (in the month of August) in this study were found to be 20-30 mm, 65-75 mm, 115-125 mm (and 155 mm for females only). In a 1983-1985 study in the Rhode River, Hines et. al. (1987) determined modes existed at 25 mm, and 75 mm for males, and 25 mm, 75 mm, and 155 mm, for females (in November). Similarly, Lippson (1979) found a peak that he termed young-of-the-year crabs of 11-30 mm in the Bay in November, 1969, along with a peak at 80-90 mm. Finally, Orth and van Montfrans (1987) found a large mode in size classes of 25 mm and less in the York River to occur between September and November each year (1983-1986). Peaks in population size structure have thus been consistently described in recent years.

Assigning ages to these peaks is difficult; however, consideration of life-history characteristics is helpful. This, and previous, research indicate that individuals which are 20-30 mm in August are young-of-the-year--which were spawned in May or June, and required 3-4 months of growing time in which to reach about 25 mm (Lippson, 1979; Hines et. al., 1987, Orth and von Montfrans, 1987). It is possible that these individuals were spawned the previous fall, however, if so, they would have had five to six months of growing time, and would be larger than 20-30 mm at one year of age. Furthermore, if individual crabs live between 2 and 3 years, as believed, it is doubtful that a crab could reach 200+mm if it were only 20-30 mm after its first year. The second mode, at 65-75 mm, is interpreted as the one year old cohort--these are crabs which have had six to eight growing months in which to molt 4-5 times (Newcombe, 1949; Truitt, 1939), thus reaching this size, which seems appropriate, given experimental estimates of growth rate (Jones et. al., 1983). The next mode is at 115-125 mm; research shows that crabs which are 65-75 mm require 2 molts to reach the 103-133 mm size range (Newcombe, 1949; Truitt, 1939). These two molts probably occur in the 6-8 months of growing time between the first and second years, therefore, the 115-125 mm mode is interpreted as a 2 year old cohort. Female crabs also exhibit a fourth mode, at 155 mm, which is not apparent with males; these are crabs one molt later. The 1987 survey and the literature indicate that this is the terminal molt (increasing from approximately 115 to approximately 145 mm) (Hines, et. al., 1987; Newcombe, 1939). Tsai et. al. (1984) suggest that immature females undergo the terminal molt upon reaching about 100 mm in length; however, this is inconsistent with the 1987 survey, Newcombe (1939), and Hines (1987). The 1987 data shows that the average size of immature females caught in commercial crab pots was 116 mm. This average may be slightly biased due to gear selectivity, but this estimate, combined with the literature support the idea that the terminal molt does not occur at 100 mm for the typical female Chesapeake Bay blue crab--rather, two molts occur between the sizes of roughly 100 mm and 150 mm. Some females undergo the terminal molt in the fall of their second year, however some delay maturity until the following season (Truitt, 1939). Thus, the 155 mm mode is between 26 and 38 months (depending on the timing of the terminal molt). The mode at 155 mm is consistently observed (throughout the year)--this suggests that this is the average maximum size that females reach. The reason this size class is not seen in the males may be that fishing mortality is greater on males at these larger sizes (some crabbers reject taking females either due to alleged difficulties in picking, or belief that they should be spared for reproduction.

(2) Formulation of Growth Curves

Using the results of the length-frequency aging technique, growth curves for each sex were constructed by plotting the carapace width modes (obtained from age distributions) over time (figure 2.9). Since crabs do not molt (grow) in the winter months, the curve exhibits plateaus of constant size during the period from November to April. A spawning date of June 1 was assumed, and the points corresponding to the length-frequency modes were connected by straight lines to obtain a partial curve. To complete the curve, the assumption that the relation between points is linear was made; with this assumption, and the winter periods of unvarying growth, the curve could be completed (figures 2.10, 2.11, 2.12).

Comparison of the curves indicates that growth is approximately the same for each sex, through 1 year of age, with females growing slightly slower. Growth beyond 2 years could not be compared because the lack of modes at larger sizes prevented the growth curve for males from being extended past 2 years. However, an approximate description of the male growth pattern was completed with the assumption that the pattern of growth for males 2.16 years old through 3.16 years old parallels that of the females for the same age interval.

The empirical growth curve derived for Chesapeake Bay blue crabs is different from the models typically used in fisheries management. Traditionally, models for growth have been useful in predicting size at age for continuously growing individuals, or average size at age for populations of continuously growing individuals (Beverton and Holt, 1957; Ricker, 1954; McCaughran and Powell, 1977). The most commonly used growth model in fisheries management is the von Bertalanffy growth equation, which stems from the relationship in figure 2.13. The model is based on the premise that at any point in time, there is a difference between L_{inf} and l_t, the length at time t; and the rate of growth is proportional to the difference between the length and a maximum asymptotic size, L_{inf}. This relationship can be written:

$$\frac{dl_t}{dt} \S L_{inf}-l_t \qquad (2.1)$$

Where K is defined as the constant of proportionality. Therefore, the derivative of length with respect to time is:

$$\frac{dl_t}{dt} =-K(L_{inf}-l_t) \qquad (2.2)$$

K is negative because the difference between L_{inf} and l_t decreases with increasing size. This has the well-known solution:

$$l_t=L_{inf}(1-e^{-Kt}) \qquad (2.3)$$

Problems often arise when classical growth models (like the von Bertalanffy) are utilized to describe crustacean growth because: (1) crustaceans do not grow continuously--growth in crustaceans consists of a stepwise series of growth increases resulting from a molting process; and (2) there is no morphological structure (such as annuli in fish) from which age is easily determined (McCaughran and Powell, 1977; Millikin and Williams, 1984). In response to these difficulties, three methods of growth assessment have previously been used: (1) Petersen's method, which involves deduction of growth from modes in length-frequency distributions; (2) observations of growth in captivity; and (3) mark and recapture experiments (Hillis, 1979; Botsford, 1987; Nicholson, 1979). This study utilized Petersen's method, which assumes that polymodality of length-frequency data reflects the underlying age structure of a population. The major disadvantages of such an approach are: (1) different solutions can often be obtained for the same sets of data, depending on the subjective interpretation involved; and (2) the parameters for the more poorly represented older year classes tend to be less reliably estimated (Nicholson, 1979). Powell (1979) suggests that these problems may be alleviated by verifying estimates of age obtained from length-frequency distributions against estimates obtained through other aging techniques, such as laboratory or tag and recapture studies. Few data are available on either blue crabs in captivity, or tag and recapture studies, therefore, verification of estimated ages is difficult; however, comparison with the literature indicates that the ages assigned are consistent with other studies on the blue crab (Hines et.al., 1987; Lippson, 1979; Orth and van Montfrans, 1987), and that the empirical growth curve is a reasonable first approximation.

In order to estimate weight-at-age, which is required for later yield-per-recruit analysis, growth data in the form of average width and weight at length were obtained from historical laboratory studies (Jones et. al., 1983). These data were utilized to create weight-at-width curves by sex (table 2.6) (figures 2.14, 2.15). Using the derived estimates of width-at-age and the width-weight curve, estimates of weight at age were made (tables 2.7, 2.8).

(3) Estimation of von Bertalanffy Growth Parameters

Despite the fact that blue crabs do not grow continuously, estimation of von Bertalanffy growth parameters is useful in that growth parameters between different blue crab studies may be compared, and growth, regardless of species, can also be compared. Maximum average attainable size--the size which would be obtained if the crab continued to live and grow indefinitely (according to the pattern of $l_t = b - ce^{-Kt}$) (Ricker, 1975), was estimated empirically by observing each of the daily effort-adjusted pot length frequency distributions, to determine which of the 20 size classes contained the largest crab(s) for that day. The catch-per-pot (CPP) corresponding to that size class was noted for each sampling day; these daily CPP values were grouped by size class (table 2.9), so that sampling days with the same largest size class were in the same group. CPP was summed by size class in two stages to obtain a total for the first part of the summer (5/23-7/09), and a total for the second part of the summer (7/10-8/12). This division was made based on the dramatic shift observed in the average CPP for the Bay as a whole (figures 2.16, 2.17). A weighting equation of the form:

$$\bar{Y}_w = \frac{\Sigma\, w_i Y_i}{\Sigma\, w_i} \qquad (2.4)$$

was used to obtain an estimate of L_{inf}. An average L_{inf} for each sex for the entire summer was determined from the two partial estimates.

Although this analysis is approximate, the parameter estimates they produced are comparable to those derived from other methods. Jones et. al. (1983) estimated L_{inf}= 180 mm for males as compared to the 174.25 mm obtained in this study. Rothschild et. al. (1988) found an L_{inf}= 176.

Estimation of an average L_{inf} and length-at-age allowed empirical estimation of K, the Brody-Bertalanffy growth coefficient; for species such as the blue crab for which length (width)-at-age is uncertain, the Walford-Ford technique to estimate K is often used. The Walford-Ford equation is derived from the intuitive knowledge that the point ($L_{inf(t)}$, $L_{inf(t+1)}$) should be the same, given that the same species is studied. In other words, a species specific L_{inf} exists, regardless of age. The equation is found by simultaneously solving:

$$l_t = L_{inf}(1-e^{-Kt}) \qquad (2.5)$$
$$l_{t+1} = L_{inf}(1-e^{-K(t+1)}) \qquad (2.6)$$

This results in a linear equation if l_{t+1} is regressed on l_t, and the slope of the line is e^{-K}.

Normally, l_{t+1} versus l_t is regressed, and a single line, with slope e^{-K} results. However, because the blue crab does not grow continuously, a constant K for all ages (sizes) cannot be assumed.

To determine K, the negative natural logarithm of the slope of the lines connecting width at age 2 (t) and 14 months (t+1) and L_{inf}, age 14 and 26 months and L_{inf}, and age 26 and 38 months and L_{inf} was found for each sex (figures 2.18, 2.19). These values of K were then averaged to find the mean K--the average growth coefficient for each sex. These admittedly rough methods of estimating the growth parameters of the blue crab population yielded the values of L_{inf} and K shown in table 2.10 and figures 2.18 and 2.19.

As earlier stated, the methods used herein, are simply approximations--they are not techniques which produce rigorous estimates. Problems inherent in these techniques include: (1) the commercial survey was designed to be only a one-year pilot study, and there is no guarantee that the year surveyed is representative of other years; (2) the gear selectivity problem, and the question of whether the scrape and pot data combination can be considered to include the entire population; (3) the statistical methods utilized to estimate L_{inf} and K rely on many assumptions regarding size and weight at age; (4) intense fishing would serve to reduce the number of very large crabs, and thus may decrease the estimate of L_{inf}. Comparison of these results with those of Rothschild et. al. (1988) indicates that the growth coefficient estimated here (0.7 for sexes combined) is approximately 2/3 that previously estimated (1.08); which is due to differences in age assumptions between the two studies.

An interesting facet of the results obtained here is that crabs grow faster at larger sizes, an idea which is counterintuitive in any species, and particularly so in the blue crab, which has been shown to molt most frequently at smaller sizes. However, the frequency of molting is only one component of blue crab growth. The second component is the magnitude of the growth increment at each molt. Although molt frequency is greater for younger crabs, molt increment is probably larger for older crabs, thus producing greater growth coefficients for older crabs.

2.2.2 Mortality

There can be many causes of death among the individuals in a population: removals by man (fishing), predation, disease, accident, etc, each with its own rate. In practice, sources of mortality are divided into two types: (1) removals by man (fishing mortality); and (2) mortality from all other causes (natural mortality) (Ricker, 1975). Each kind of mortality has its own instantaneous rate (fishing mortality rate=F, natural mortality rate=M), and the sum of these is the instantaneous total mortality rate (Z=F+M).

Beverton and Holt (1957) illustrate that an approximation of the instantaneous rate of total mortality (Z) can be obtained from:

$$Z = \frac{1}{\text{Average age after recruitment to the fishery}} \qquad (2.7)$$

where the average age after recruitment is calculated as follows (figure 2.20): the number of individuals at each age is determined from sampling data (Robson and Chapman, 1961; Chapman and Robson, 1960). Ages are then coded by assigning consecutive integers to each age beginning with 1 at the age at recruitment. Thus, if the age of recruitment is 2 years, as in figure 2.24, age 2 would be coded 1, age 3 coded 2, and so on. The number of individuals at each coded age is then multiplied by the coded age (N*coded age). The average age after recruitment can be found by dividing the total N*coded by the total number of individuals at each coded age. Equation 2.7 can then be solved.

The abundance of blue crabs by age is unknown, therefore, in this study, the average age after recruitment was estimated empirically from crabs which were recruited to the pot fishery. The average carapace width of all crabs caught, by sex, on each pot sampling day was determined (table 2.11). The total average carapace width was derived by summing the daily average carapace width, and dividing by the total number of pot sampling days (82); the total average size was found to be 134 mm for males and 141 mm for females. Although the growth curve for males did not extend past 125 mm, a rough approximation of the age at 134 mm was made. The growth curve indicates that males are 125 mm in August of their second year. In each of the previous years, growth between August and November is significant; males grow from 25 mm in August to 32 mm in November in the year they are spawned, the following summer, they grow from 75 mm in August to 87 mm in November. Therefore, it seems reasonable to assume that males which are 125 mm in August of their second year should reach at least 135 by November of that year. This suggests that males of 134 mm are approximately 2.4 years old.

Average age for each sex after recruitment to the pot fishery could then be determined with the knowledge that the age at recruitment to the pot fishery is 25 months (or 2.08 years at 125 mm). The average age after recruitment is the average age in the pot fishery less the age that crabs are first recruited to the pot fishery. Therefore, from equation 2.7:

$$Z = \frac{1}{29 \text{ mo.} - 25 \text{ mo.}} = \frac{1}{4 \text{ mo.}} = \frac{1}{1/3 \text{ year}} = 3.0$$

This estimate of total mortality rate is the sum of the fishing rate in the pot fishery and the natural mortality rate. However, blue crabs enter the peeler fishery long before they recruit to the pot fishery. To estimate the total mortality previous to the pot fishery, we again use formula 2.7. We know that the average age in the pot fishery is about 29 months. We also know that crabs are recruited to the crab (peeler) fishery at 14 months (or 1.16 years at 75 mm). Therefore:

$$Z = \frac{1}{29 \text{ mo.} - 14 \text{ mo.}} = \frac{1}{15 \text{ mo.}} = \frac{1}{1\ 1/4 \text{ yr.}} = 0.80$$

This is a rough estimate of the total mortality rate, which is the sum of the fishing mortality rate (for the interval from recruitment to the peeler fishery and recruitment to the pot fishery) and natural mortality rate.

The data obtained in this study did not facilitate estimation of the rate of natural mortality (M); however, a rough approximation of M can be derived from the blue crab life history. If we suppose that the population of crabs is never fished, and know that individuals live about 3 years, we could estimate the average age of that population to be approximately 1.5 years. Since there is no fishery, there is no age at recruitment to the fishery, and since Z=F+M, and F=0, then Z=M and:

$$Z = M = \frac{1}{\text{average age}} = \frac{1}{1.5 \text{ yr.}} = \frac{1}{3/2 \text{ yr.}} = 0.67$$

(Note: this assumes that the period of high juvenile mortality has passed, and the mortality rate has stabilized).

Now, that we have an approximation of M, we can estimate F for the pot fishery:

$$Z = F + M \Longrightarrow F = Z - M = 3.0 - 0.67 = 2.33$$

and for the peeler fishery:

$$F = 0.80 - 0.67 = .13$$

So, we estimate that the lower bound of fishing mortality is on the magnitude of 0.13 and the upper bound is on the magnitude of

2.33. These are simply approximations, but they do provide a point of departure for further analyses.

2.2.3 Equilibrium Yield-Per-Recruit Analysis

Empirical estimates of growth and mortality were used to complete a yield-per-recruit analysis. The speculative nature of the mortality estimate suggested that determining the yield-per-recruit at a range of mortalities would be prudent; however, these analyses are very time consuming. Therefore, a microcomputer based fortran program, FMBRIKR (Gales, 1964), was used to fit the data to the Ricker model. FMBRIKR is designed to compute an approximate yield isopleth for a given number of recruits to a fishery when both growth and natural mortality are estimated empirically. All calculations are carried out using Ricker's method for estimating equilibrium yield. Program results were verified by comparing several tabular results (calculated by hand) to computer output (tables 2.12, 2.13, 2.14). Six different natural mortality rates (M=0.3, 0.4, 0.5, 0.6, 0.7, and 1.0) , combined with six different fishing mortality rates (.35, .70, 1.05, 1.40, 1.75, 3.0) were tested for each sex.

Figures 2.21 and 2.22 present the results of the analysis in the form of yield-per-recruit versus fishing mortality, with age-at-first-capture held constant. Figure 2.21 indicates that the greatest yield is obtained for the large crabs (155 for F<2.0 and 145 for F>2.0). The greatest yield-per-recruit is obtained at a fishing mortality of 3.0, and the size-at-first-capture being 145 mm. Interesting points to note from figure 2.21 are that yield-per-recruit is relatively insensitive to mortality rate (compare figures a, b, c); and that the yield produced for the size-at-first-capture now used (125 in pot fishery) is approximately one-half that which could be obtained if the size-at-first-capture were raised to 145 mm (~6.0 inches). Figure 2.22 demonstrates that the greatest yield is obtained at age 2.8 (124 mm) at all levels of fishing mortality (with the exception of crabs with a natural mortality rate of 0.3, and a fishing mortality of 3.0). The highest yield-per-recruit can be obtained at a fishing rate of 3.0 and the age-at-first-capture being 2.8. A comparison of figures 2.21 and 2.22 shows that results are different between genders although fishing mortality and natural mortality are the same; this is due to the difference in growth rate between the sexes (males grow more rapidly than females). The management strategy is similar for the sexes: delay fishing until crabs reach a fairly large size (124 mm for females and 145 mm for males), and then fish them intensively.

Figures 2.23 and 2.24 present the results of the analysis in the form of yield-per-recruit versus age-at-first-capture, with fishing rate held constant. Figure 2.23 shows that the greatest yield (for males) is obtained when the size-at-first-capture is 145-155 mm for all fishing mortality rates, and the that the greatest yield can be obtained with an F of 3.0 and the size-at-first-capture being 145 mm. Females (figure 2.24) demonstrate a similar pattern, with the greatest yield obtained with an F of 3.0 and the size-at-first-capture being 124 mm.

Figures 2.25 and 2.26 illustrate that fishing mortality and age-at-first-capture can be varied simultaneously. This is done by plotting F and age-at-first-capture on the X and Y axes, respectively, and drawing lines through numerically equal values of yield-per-recruit. Thus, we obtain a yield-per-recruit diagram, demonstrating how yield-per-recruit varies with changing fishing rate and age-at-first-capture. These contour diagrams allow the determination of the maximum yield-per-recruit for any size at recruitment to the fishery, and the rate of fishing necessary to obtain this yield. In interpreting the figures, for any given rate of fishing (F), the maximum yield-per-recruit can be determined from the point where a vertical line from F is tangential to a contour's left edge. For example, in figure 2.25a, a perpendicular line from F=1.5 would graze the 35 gram contour, and referring this point to the vertical axis, the maximum yield would be obtained (for F=1.5) when crabs enter the commercial fishery at approximately 2.1 years (mean carapace width = 124 mm). Thus, 1,000 crabs of age 0.91 years minus the number dying from natural causes would yield 35 grams per crab if F=1.5 and if the age-at-first-capture is 2.1 years.

From the yield contour diagram it is also possible to find the maximum yield for any size at recruitment by extending a horizontal line from a given age to the point where it is tangential to the bottom of a yield contour. The rate of fishing necessary to obtain this yield can then be found by extending a vertical line from this point to the X-axis below. In figure 2.25f, the maximum yield-per-recruit for those crabs entering the commercial fishery at 1.5 years of age (~90 mm) would be about 5 grams and the necessary rate of fishing in order to obtain that yield would be about 3.0.

The effect of doubling the instantaneous natural mortality rates on the yield of males is shown in figures 2.25a and 2.25d, and figures 2.26a and 2.26d for females. For identical rates of fishing, the yield of males would decrease by about 34-48%. Similarly, the yield of females would decrease about 45-58% with a doubling of the annual instantaneous mortality rate from 0.3 to 0.6.

Although few data points were available for the construction of a growth curve, and mortality rates were only roughly estimated, the results of this analysis are significant in that they showed (for all natural mortalities tested) that yield-per-recruit is lost if males are fished before they reach 145 mm (5.7 inches) and females are fished before they reach 124 mm (4.9 inches). This suggests that the present minimum size of 3.0 inches for peeler crabs constitutes overfishing in the yield-per-recruit sense. Furthermore, the current minimum of 125 mm in the pot fishery is acceptable for females, but should be higher for males to optimize yield-per-recruit.

2.3 Recruitment-Stock Relationship

INTRODUCTION

The historical Chesapeake Bay commercial reported blue crab landings are variable; a paramount problem in explaining the year-to-year variability is the characterization of the relationship between recruitment and stock.

MATERIALS AND METHODS

A recruitment index was developed from a sampling of the commercial Smith Island scrape fishery, conducted from 1948-1981. Data were collected from the fishery as follows: (1) a once weekly measurement of the size and sex composition of the first 200 crabs captured by the same commercial crabber (Edward Harrison of Smith Island, Maryland) for each week throughout the season, and (2) daily catch-per-effort data (number of crabs-per-man-per-day) for a subsample of the fishery on Smith Island. The recruitment index was developed by combining these data. Recruits were defined as crabs less than 75 mm carapace width (sexes combined). Seventy-five mm was chosen as the dividing line because 75 mm (~3 in.) is the minimum legal size for peeler crabs; table 2.15 presents the recruitment index derived from the Smith Island scrape fishery data, and the total reported commercial catch for Maryland and Virginia combined (hard and soft crabs) (MDNR, VMRC), which is an approximate measure of stock abundance. Catch was then plotted versus the recruitment index (lagged 2 years) (figures 2.27, 2.28).

RESULTS AND DISCUSSION

Results indicate that although there is no evidence for any specific recruitment-stock model, there does appear to be a relationship between recruitment and stock. If no relationship existed, figure 2.27 would be a straight line, furthermore, if the straight line which would most adequately fit the data is plotted, it predicts the production of recruits at 0 stock level, which is obviously not possible. Therefore, some sort of curvilinear relationship between recruitment and stock must exist. Figure 2.27 indicates that each decade, the 1950's, the 1960's, and the 1970's, differed in its recruitment-stock relationship. The early 1950's, in particular, 1950 and 1952 were good years, because they indicated production of a large number of recruits from a moderate stock size; the late 1950's show lower levels of stock (catch) which produced moderate to low recruitment. The 1960's, particularly 1962, 1964, and 1968 were poor years, as they generally showed moderate to high levels of stock (catch) producing low levels of recruitment. The early 1970's suggest moderate to low stock and moderate recruitment. In general, it appears that the decade of the 1960's was the least productive in that the level of the stock was consistently high, yet recruitment was consistently low. This corresponds to the traditional Ricker theory that at high levels of stock, production of recruits is decreased. For a short-lived species like the blue crab, the fact that the stock consistently remained at a high level despite the consistent production of low numbers of recruits seems to indicate that either: (1) fishing mortality does not significantly reduce the stock; or (2) the period of high fishing mortality occurs so late in the life span of the species, that the effect is minimal.

Although a recruitment-stock relationship must exist, the nature of the relationship is difficult to characterize. Figure 2.28 indicates that in some years, recruitment tracked stock fairly well, as in the 1950's, yet, in other years, appears unrelated. The fact that for virtually equal levels of stock (1948 and 1949), recruitment could vary from 30,000 to 60,000 suggests that either environmental effects have a dramatic effect on recruitment, or that the precision of these measures of stock and recruitment is low.

This analysis is consistent with Rothschild's (1986) conclusion that a sort of recruitment-stock paradox exists; although long-term population stability suggests that strong relation of stock to recruitment should be expected, empirical evidence suggests that the relation is vague, in that the variance around the theoretical relationship seems fairly large.

2.4 Production

2.4.1 INTRODUCTION

Empirical estimation of production required construction of catch curves. A catch curve is simply a graph of the logarithm of the number of individuals taken at successive sizes (Ricker, 1975); these curves have traditionally been widely used in estimating age-specific survivorship. Catch curves typically have a steeply ascending left limb, a dome shaped upper portion, and a long-descending right limb. The ascending left limb and the dome of the curve are thought to represent size classes which are incompletely captured: that is, the gear takes them less frequently in relation to their abundance than the larger classes (Ricker, 1975). The more informative portion of the curve is therefore the descending right limb, which is typically interpreted as an age or size-specific survivorship curve (provided certain conditions are met) (Baranov, 1918; Ricker, 1975).

2.4.2 MATERIALS AND METHODS

The catch-per-pot by 10 mm size class by sex was obtained for early and late in the season. The natural log of the catch-per-pot versus the size class (midpoint) was then plotted to create early and late season catch curves (figures 2.29 and 2.30).

2.4.3 RESULTS AND DISCUSSION

The catch curves constructed indicate an increase in the catch-per-unit-effort over all size classes between the first part of the season and the second part of the season. This increase may be due, in some degree, to immigration into the areas sampled, however, it is more likely that the surplus in CPUE is due to the entry of new recruits to each size class. If this surplus CPUE is multiplied by the average weight at each size class, and then multiplied by the amount of effort required to capture these crabs, then an estimate of the production in the 1987 pot fishery can be made.

In 1983, Tang (1983) believed that the blue crab fishery had entered a state of decline, and that conservation measures such as quotas, and restrictions on commercial and recreational fishing were necessary. This study suggests that the conditions in 1987 were different from those in 1983 (when Tang felt that the stock was declining) and that a surplus of biomass was produced in the 1987 pot fishery.

Chapter 3.
Sex Ratios

3.1 INTRODUCTION

Sex ratio is an important aspect of the population dynamics of a species. T. C. Emmel (1976) states that sex ratio phenomena are of particular importance in population dynamics, because where a reduction in the percentage of one sex (especially females) occurs, there is likely to be a reduction in the rate of population growth. Measurement of sex ratio can yield important information on the population dynamics of a species. This can vary from a simple qualitative observation of an expected shift in proportions that signifies major changes in population structure to quantitative analysis to estimate abundance and removals. As a fishery develops, it is important to document the changes in the size composition and sex ratio of the stocks. These data, together with catch and effort statistics are required to assess the effect of fishing on abundance. Sex ratios are altered by differential mortality between males and females at different times in the life history; however, the sex ratio may also be affected by factors such as exploitation by a fishery--particularly fisheries which place a greater value on one or the other sex. Potential reasons for a shift in sex ratio in a blue crab population from 1:1 to male biased or female biased include differential mortality, immigration, or emigration (figure 3.1).

The potential effects of altering the natural proportion of each sex in a population may be quite serious, therefore, analysis of the sex ratio of a commercially important population deserves attention. In order to determine what (if any) effect the fishery (and other factors) has on a population, a description of the "normal" or "natural" state must be completed (Rothschild, 1986). This "natural" state is difficult to characterize, particularly when changing environmental variables, different migratory patterns between the sexes, and fishing are occurring. Several studies on the sex ratio of blue crabs have been completed, but with no conclusions as to long-term changes made (Millikin and Williams, 1984; Abbe, 1983).

3.2 Change in Ratios Estimators

Measurement of changes in sex ratio has been widely used in wildlife management to quantitatively estimate abundance and removals through techniques known as change in ratios estimators (Paulik and Robson, 1969; Petrides, 1949; Rupp, 1966; Lander, 1962). The change in ratios (CIR) method offers a general unified approach for estimating population abundance, productivity, and exploitation rates, and survival characteristics from changes in population composition. CIR is applicable when a population can be classified into two categories (such as male and female), and a change occurs in the relative abundance of the two types. The typical application is as follows (Paulik and Robson, 1969):

1. The fraction of a population in a certain category is either known or can be measured at time 1 (T_1).

2. A measurable change in the numbers in either one or both of

the categories occurs that alters the above fraction.

3. The fraction is measured again after the change is complete and the information is employed to estimate some characteristic of the population (such as its size at T_1).

<u>Notation</u>:

It is assumed that the population is composed of two types of animals designated X-type and Y-type; in this case, X-type may be males and Y-type, females--occasionally, problems arise in discerning males from females; however, that is generally not a problem with blue crabs. It is further assumed that a measurable differential change in the two types occurs between T_1 and T_2 (Paulik and Robson, 1969).

N_1 = total number in population at T_1

N_2 = total number in population at T_2

X_1 = number of X-type (males) in population at T_1

X_2 = number of X-type (males) in population at T_2

Y_1 = number of Y-type (females) in population at T_1

Y_2 = number of Y-type (females) in population at T_2

<u>NOTE</u>: $X_1 + Y_1 = N_1$ and $X_2 + Y_2 = N_2$

$p_1 = X_1/N_1$ = fraction of males in population at T_1

$p_2 = X_2/N_2$ = fraction of males in population at T_2

R_x = net change in numbers of males in population between T_1 and T_2

$R_x + R_y = R = N_2 - N_1$ = net removals from population between T_1 and T_2

$f = R_x/R$ = fraction of in total removal ($0 \leq F \leq 1$)

<u>NOTE</u>: f is defined only when R_x and R_y have the same sign.

The quantities defined above are used as population parameters. Applications of CIR methods usually require sample surveys of some type to obtain estimates of one or more population parameters (Paulik and Robson, 1969). Counts obtained in sample surveys are designated by lower case letters corresponding to their counterparts in the population. Estimates of population parameters are indicated by a caret over the symbol for the parameter.

The accuracy of the estimates obtained is dependent upon the accuracy of the required "true" sex ratio (M:F) and the catch data. The assumptions and data requirements of the CIR are as follows:

<u>Assumptions</u>:

1. The population is closed during sampling periods.
2. The population is closed except for removals during the removal process.
3. The probability of capture within each sampling period is constant for all units of effort and equal for all individuals in the population.
4. The probability of capture during sampling periods is equal for males and females.
5. Full geographic distribution is sampled.
6. Full temporal distribution is sampled.

<u>Data Requirements</u>:

1. The number caught in each unit of effort during sampling periods is known.
2. The number caught in each unit of effort during removal periods is known.
3. The number of males and females caught in each unit of effort is known.
4. Catch rate is sufficient to support a rigorous evaluation.

General Formulas:

Using the defined symbols, the fraction of males in the population at T_2 can be written as the ratio of: (the number of males at T_1 corrected for the changes that have taken place in the males class between T_1 and T_2) to (the total number of animals in the population at T_1 corrected for the changes that have taken place between T_1 and T_2) (Paulik and Robson, 1969).

That is,

$$p_2 \frac{p_1 N_1 + R_x}{N_1 + R} \tag{3.1}$$

From this equation (1), a number of different CIR estimates can be derived by solving for the parameter to be estimated in terms of quantities that are either known or whose values can be estimated from sample surveys.

A) Absolute abundance of the population and its components (routinely estimate either N_1 or X_1).

From (3.1), obtain:

$$N_1 = \frac{R_x - p_2 R}{p_2 - p_1} \tag{3.2}$$

This is usable whenever p_1, p_2, R_x, and R are known or can be estimated (Paulik and Robson, 1969; Petrides, 19XX; Rupp, 1966)

$$X_2 = \frac{p_2(R_x - p_2 R)}{p_2 - p_1} \tag{3.3}$$

In the classic dichotomy estimation problem:

p_1 = fraction of males in population just before fishery (season)
p_2 = fraction of males at end of fishery (season)

p_2 = fraction of males at end of fishery (season)
R_x = total catch of males during fishery (season)
R_y = total catch of females during fishery (season)

Commonly, values of p_1 and p_2 would be estimated by pre- and post-season (fishery) surveys and R_x and R_y determined by total counts.

NOTE: From (3.2): $N_2 = \dfrac{R_x - p_1 R}{p_2 - p_1}$ = size of population just after change caused by removal of R_x and R_y.

B) Rate of exploitation (fraction of the initial population removed by man during a specified time interval (Ricker, 1975)).

Recall (3.1): $p_2 = \dfrac{p_1 N_1 + R_x}{N_1 + R}$

By dividing numerator and denominator by N_1 and solving for

$\dfrac{R}{N_1} = \mu$:

$$\mu = \frac{p_1 - p_2}{p_2 - f} \tag{3.4}$$

exploitation rate (can be determined for males or females)

C) Survival Rates

Introduce S_x = fraction of males surviving from T_1 to T_2

S_y = fraction of females surviving from T_1 to T_2

Number males at T_2 is: $X_2 = X_1 S_x = p_1 N_1 S_x$

Number females at T_2 is: $Y_2 = Y_1 S_y = (1 - p_1) N_1 S_y$

Total population at $T_2 = N_2 = p_1 N_1 S_x + (1 - p_1) N_1 S_y$

Substituting in (1), obtain:

$$p_2 = \frac{p_1 N_1 S_x}{p_1 N_1 S_x + (1 - p_1) N_1 S_y} \qquad (3.5)$$

Algebraic manipulation ==>

$$\frac{S_x}{S_y} = \frac{1 - p_1}{p_1} \frac{p_2}{1 - p_2} \qquad (3.6)$$

where $\frac{S_x}{S_y}$ is survival rate of males relative to females.

Since $(1 - p_1)/p_1 = Y_1/X_1$, the number of females at T_1, divided by the number of males at T_1, $(1 - p_2)/p_2 = Y_2/X_2$, the above equation (3.6) can be written

$$\frac{S_x}{S_y} = \frac{Y_1}{X_1} \frac{Y_2}{X_2} \qquad (3.7)$$

<u>NOTE</u>: when the sex ratio (M:F) is 1:1, the formula becomes:

$$\frac{S_x}{S_y} = \frac{p_2}{1-p_2} \frac{X_2}{Y_2}$$

<u>Variance Computations</u>:

Variances of the individual estimates that go into a CIR estimator can often be found by direct means, but what is needed is a method for combining them to determine the variance of the final parameter estimate. Paulik and Robson (1969) discuss methods for determining the variance of the final estimate, as well as for the construction of confidence intervals for estimates.

3.2.1 MATERIALS AND METHODS

Using the 1987 commercial pot fishery survey data, CIR methods were applied, with the realization that resulting estimates would be approximate, since many required assumptions were not met, and additional assumptions were made to create the required information.

The fishery was divided into early and late seasons, as described in chapter 2, on the basis of a marked shift in apparent abundance (catchability). The number of crabs of each sex caught in each season was counted. In the early season sampling, 16,348 of 24,339 crabs caught were males, and in the late season, 10,349 of 14,601 crabs caught were males. From the 1987 total reported commercial catch estimate of 36,528 metric tons (4620 lbs), and the observation of Rothschild et. al. (1988) that average sex ratio in commercial crab pots was 67% male, it was estimated that the total removals (catch) in 1987 was 24,427 metric tons male and 12,054 metric tons female.

Therefore:

$$P_1 = \frac{16,348}{24,339} = 0.67$$

$$P_2 = \frac{10,349}{14,601} = 0.71$$

$$R_x = -24,474 \text{ metric tons}$$

$$R = R_x + R_y = -36,528 \text{ metric tons}$$

And, according to (3.2),

$$N_1 = \frac{(-24,474 \text{ mt}) - [(0.71)(-36,528 \text{ mt})]}{(0.71)-(0.67)}$$

$= 36,522$ mt: the total poundage of males in the population at time 1.

3.2.2 RESULTS AND DISCUSSION

This analysis is not meant to be viewed as an absolute estimate, it is simply presented as an example of the potential use of the correct basic sex ratio and catch data. Problems inherent in the above calculations include: (1) the survey completed sampled all crabs caught, regardless of whether or not they were kept--in spite of this, the sample sex ratio was assumed to have been the true sex ratio of all crabs actually removed; (2) since the major gear in the fishery is crab pots, it was assumed that the total reported catch was caught predominantly by pots and that an adequate estimate of removals by the pot fishery could therefore be derived from it; (3) the fishery as it was sampled does not satisfy a number of the assumptions required for the proper utilization of change in ratios techniqes.

Using the general formulae given, and the proper sex ratio information, the rate of exploitation and natural mortality of the population could also be determined, along with their associated variances and confidence intervals.

The assumptions and data requirements of CIR methods could most easily be met with use on data from the dredge fishery, since the population is, in essence, closed during the winter. In order for all individuals to have an equal probability of capture, gear modifications, such as a fine mesh liner, would probably need to be used. The location of the sampling would probably have an impact on the equality of the probability of capturing each sex; however, with the life history of this species, it may have to be overlooked. This should not create a problem, since the same bias in the sex ratio would be present at both T_1 and T_2, due to the fact that the population is effectively closed.

CONCLUSIONS

The objective of this work was to complete a stock assessment of the Chesapeake Bay blue crab population using the data which are currently available. The importance of completing a stock assessment is reflected by the abundance of important questions which watermen and managers alike are attempting to address. In September, 1988, a workshop of scientists and managers was held in order to address what were deemed as the most persistently asked questions regarding the blue crab fishery (figure 3.2). The results of this study provide information on these concerns.

Several of the questions most important to those involved with the fishery are related to the yield-per-recruit problem, in particular the question of the possibility of overfishing. With regard to the overfishing issue, this study indicates that fishing male crabs before they reach 145 mm (~5.7 inches) or female crabs before they reach 124 mm (~4.9 inches) constitutes yield-per-recruit overfishing. Therefore, raising the minimum size limit (and mesh size of pots and scrapes) should increase the yield-per-recruit of future landings.

The recruitment-stock relationship is another important point which must be addressed to answer many questions. The primary issue is whether there is, in fact, a relationship at all, and this research indicates that a (weak) relationship exists; this finding research indicates that a (weak) relationship exists; this finding is important, as it suggests that the harvest of crabs in any year will somehow affect the number of future crabs. The blue crab population could therefore conceivably be overfished, if stock size were consistently reduced to a level which significantly reduced recruitment.

This research further indicates that the quotas, limited access, and restrictions on recreational fishing recommended by Tang (1983) are probably too severe at this time, because production does seem to be occurring. It does suggest, however, that minimum size limits should be raised in order to maximize yield-per-recruit. For males, a single limit of 6.0 inches, regardless of maturity condition would increase yield-per-recruit significantly. For female crabs, a single limit of 5.0 inches is recommended in order to increase the yield-per-recruit; this greater size may also benefit reproduction, in that additional females (not taken by the peeler fishery) would have the opportunity to spawn. Finally, no specific critical stock size was determined here, however, because recruitment and stock are apparently linked, the size of the stock is an important factor which must be considered.

The migrations of the blue crab throughout the Chesapeake Bay, indicate that all parts of the stock are interconnected, and the entire Bay and its tributaries are involved--for example, fishing in Maryland affects the future availability of crabs for dredging, potting, and reproduction in Virginia (Cronin, 1987). Therefore, no single agency can effectively manage all of the component parts; effective management is dependent upon coordination among the agencies regulating Maryland, Virginia, and the Potomac River. Although blue crabs need to be managed on the level of the entire Bay, uniform regulations are probably not the solution; the migratory behavior of blue crabs suggests that utilization of standard regulations for the entire Bay may be impractical (Cronin, 1987). In this case, cooperative management does not necessarily mean uniform regulations, but does require standard goals and objectives among all management agencies.

Appendix A

Tables

Table 1.1. Summary of the laws and regulations relating to blue crab gears in Chesapeake Bay.

	Maryland	Virginia	Potomac River
Maximum Amount of gear per person or per boat			
Pots	-------	-------	-------
Trotlines	-------	-------	--------
Dredges	2 per boat	2 per boat	not legal
Scrapes	2 per boat	2 per boat	not legal
Maximum dimensions of gear			
Pots	minimum mesh size 1 in.; maximum length of sides 24 in.	minimum mesh size 1.5 in.[a]	-------
Trotlines	-------	-------	-------
Dredges	maximum bar width 60 in. per dredge	maximum mouth width 12 ft. combined mouth width 14 ft.	not legal
Scrapes	maximum bar width 60 in.	maximum mouth width 4 ft per scrape.	not legal
Legal Gear [b]			
	pot, trotline, scrape, dredge, bank trap, channel pound, dip net, handline, seine, hand-drawn net, scrape, collapsible trap	pot, trotline, patent trotline, dip net, hand scrape, handline, peeler pot, scrape, dredge, crab trap, crab pound	pot, trotline, dip nets, collapsible trap, handline, peeler trap

Table 1.1 (cont'd)

Seasonal Restrictions			
Pots	4/02-12/31	-------	-------
Trotlines	-------	-------	-------
Dredges	4/15-10/30	12/02-3/31 no Saturdays	not legal
Scrapes	4/15-10/30	12/02-3/31	not legal
Size Restrictions			
Hard crabs	5 in.	5 in.	5 in.
Mature fem.	-------	-------	-------
Peelers	3 in.	-------	3 in.
Soft crabs	3.5 in.	-------	-------

[a]Hard crab pots only; no minimum mesh size for peeler pots.

[b]Legal in at least a portion of the Bay or its tributaries.

----- Indicates no restrictions.

Table 2.1. Fishing mortality (F =0.35) and natural mortality (M=1.0) for male Chesapeake Bay blue crabs; and the computation of equilibrium yield from 0.418 g of recruits at age 0.91 years (11 months).

AGE	WEIGHT	ln(WT)	G	F	M	(G-F-M)	WEIGHT CHANGE FACTOR	WEIGHT OF STOCK	AVERAGE WEIGHT	YIELD
								0.4180		
0.91	0.418	0.8723	2.612	0.0000	0.09	2.542	12.7100	5.3110	2.860	0.0000
1.00	5.830	1.7630	0.810	0.0000	0.08	0.730	2.0750	11.9700	8.166	0.0000
1.08	13.000	2.5646	0.540	0.0000	0.08	0.460	1.5840	17.4360	14.240	0.0000
1.16	22.490	3.1131	0.220	0.0115	0.09	0.099	1.1035	19.2630	18.359	0.5780
1.25	28.030	3.3333	0.160	0.0280	0.08	0.052	1.0530	20.2910	19.780	0.5500
1.33	32.360	3.4921	0.180	0.0280	0.08	0.072	1.0750	21.8060	21.048	0.5890
1.41	39.390	3.6735	0.000	0.0000	0.09	-0.090	0.9140	19.9290	20.868	0.0000
1.50	39.390	3.6735	0.000	0.0000	0.08	-0.080	0.9230	18.3900	19.162	0.0000
1.58	39.390	3.6735	0.000	0.0000	0.08	-0.080	0.9230	16.9760	17.680	0.0000
1.66	39.390	3.6735	0.000	0.0000	0.08	-0.080	0.9230	15.6670	16.321	0.0000
1.74	39.390	3.6735	0.000	0.0000	0.09	-0.090	0.9140	14.3200	14.994	0.0000
1.83	39.390	3.6735	0.380	0.0280	0.08	0.272	1.3100	18.7600	16.540	0.4630
1.91	57.300	4.0483	0.290	0.0315	0.09	0.169	1.1840	22.2100	20.490	0.6450
2.00	76.500	4.3373	0.290	0.0280	0.08	0.182	1.1996	26.6430	24.427	0.6840
2.09	102.650	4.6312	0.000	0.0280	0.08	-0.108	0.8980	23.9250	25.284	0.7080
2.16	102.644	4.6312	0.1072	0.0280	0.08	-0.006	0.9942	23.7858	23.855	0.6680
2.24	111.680	4.7156	0.0396	0.0280	0.08	-0.069	0.9337	22.2090	22.997	0.6439
2.32	118.260	4.7728	0.5767	0.0315	0.09	-0.066	0.9382	20.8157	21.522	0.6780
2.41	125.270	4.8305	0.0000	0.0000	0.09	-0.090	0.9139	19.0424	19.939	0.0000
2.50	125.270	4.8305	0.0000	0.0000	0.08	-0.080	0.9231	17.5784	18.310	0.0000
2.58	125.270	4.8305	0.0000	0.0000	0.08	-0.080	0.9231	16.2270	16.903	0.0000
2.66	125.270	4.8305	0.0000	0.0000	0.09	-0.090	0.9139	14.8303	15.523	0.0000
2.75	125.270	4.8305	0.0000	0.0000	0.08	-0.080	0.9231	13.6902	14.260	0.0000
2.83	125.270	4.8305	0.1808	0.0315	0.09	0.059	1.0611	14.5270	14.109	0.4452
2.92	150.360	5.0113	0.1656	0.0280	0.08	0.058	1.0593	15.3840	14.958	0.4188
3.00	177.330	5.1769	0.1082	0.0280	0.08	0.000	1.0002	15.3903	15.387	0.4309
3.08	197.363	5.2850	0.0000	0.0280	0.08	-0.108	0.8976	13.8148	14.603	0.4089
3.16	197.360	5.2850								

Table 2.2. Monthly total of daily mean CPUE by size class, by sex for the commercial pot and scrape fishery sampling in June, 1987.

Size Class	Mean CPUE Males pots	Mean CPUE Males scrapes	Mean CPUE Females pots	Mean CPUE Females scrapes
0 - 10	0	0	0	0
10 - 20	0	0.0742	0	0.0274
20 - 30	0	0.5015	0	0.2644
30 - 40	0	1.2119	0	1.3821
40 - 50	0	1.3719	0	1.6669
50 - 60	.01	1.6649	0.024	1.9415
60 - 70	0.062	0.9283	0.044	1.8134
70 - 80	0.136	1.3343	0.171	1.4369
80 - 90	0.249	1.1282	0.504	0.7937
90 - 100	0.443	0.9097	0.685	0.6669
100 - 110	2.646	1.0035	0.764	0.6599
110 - 120	13.636	0.7954	3.093	0.2087
120 - 130	28.776	1.0341	4.343	0.1235
130 - 140	29.854	0.7238	9.116	0.1303
140 - 150	20.238	0.3317	15.040	0.3001
150 - 160	8.92	0.0969	12.177	0.1688
160 - 170	2.868	0.0052	4.925	0.0298
170 - 180	0.743	0	0.976	0
180 - 190	0.161	0	0.130	0
190 - 200	0.077	0	0.500	0

Table 2.3. Monthly total of daily mean CPUE by size class, by sex for the commercial pot and scrape fishery sampling in July, 1987.

Size Class	Mean CPUE Males pots	Mean CPUE Males scrapes	Mean CPUE Females pots	Mean CPUE Females scrapes
0 - 10	0	0	0	0
10 - 20	0	0.0520	0	0.0830
20 - 30	0	0.2373	0	0.1582
30 - 40	0	0.6928	0	0.5983
40 - 50	0	2.3946	0	1.4615
50 - 60	0.083	3.0378	0.045	3.7121
60 - 70	0.057	3.6209	0.133	5.1345
70 - 80	0.199	3.0976	0.111	5.0005
80 - 90	0.208	2.4264	0.369	3.6155
90 - 100	0.290	2.1348	0.691	3.2390
100 - 110	2.926	1.7085	0.934	2.3292
110 - 120	11.320	1.7487	2.380	1.0784
120 - 130	20.026	2.0883	1.949	0.1946
130 - 140	20.694	1.0959	5.526	0.3145
140 - 150	18.064	0.6272	8.738	0.5067
150 - 160	14.644	0.2439	10.124	0.4249
160 - 170	5.042	0.0803	5.510	0.0781
170 - 180	1.991	0	1.626	0.0080
180 - 190	0.814	0	0.458	0
190 - 200	0.150	0	0.031	0

Table 2.4. Monthly total of daily mean CPUE by size class, by sex for the commercial pot and scrape fishery sampling in August, 1987.

Size Class	Mean CPUE Males pots	Mean CPUE Males scrapes	Mean CPUE Females pots	Mean CPUE Females scrapes
0 - 10	0	0.164	0	0.061
10 - 20	0	1.42	0	0.938
20 - 30	0	3.36	0	3.35
30 - 40	0	2.31	0	1.95
40 - 50	0	0.836	0	0.996
50 - 60	0	1.39	0	1.53
60 - 70	0.024	3.04	0	8.05
70 - 80	0	3.93	0	5.30
80 - 90	0.038	2.52	0.024	4.79
90 - 100	0.139	1.47	0.578	3.59
100 - 110	1.02	1.69	1.34	3.23
110 - 120	8.79	1.79	3.53	0.972
120 - 130	17.89	1.49	1.85	1.16
130 - 140	17.18	0.844	2.36	0.583
140 - 150	14.80	0.866	5.96	0.832
150 - 160	9.79	0.231	5.83	1.78
160 - 170	3.24	0.119	2.23	0.301
170 - 180	0.827	0	0.372	0
180 - 190	0.234	0	0.036	0
190 - 200	0.106	0	0	0

Table 2.5. Estimated carapace width at age for male and female blue crabs, derived by Petersen's method of length-frequency distribution analysis.

Sex	Location of size class mode	Estimated age*
Male	20-30	~2 months
Male	70-80	~14 months
Male	120-130	~26 months
Female	20-30	~2 months
Female	60-70	~14 months
Female	110-120	~26 months
Female	150-160	~38 months

*Date of spawning assumed to be June 1

Table 2.6. Carapace width (mm) and weight (g) for Chesapeake Bay blue crabs, obtained in historical laboratory studies. (After Newcombe, 1949; Newcombe, Sandoz, and Rogers-Talbert, 1949; Van Engel, 1958).

Average Carapace Width(mm)	Males Average Weight (g)	Females Average Weight (g)
2.50	.003	0.0036
3.7	.0086	0.0098
5.10	.020	0.0220
6.6	.004	0.0043
8.6	.0081	0.0086
10.2	.130	0.1300
11.0	.160	0.1600
16.80	.49	0.4800
21.10	.89	0.8600
33.9	3.17	2.9100
45.3	6.87	6.1300
55.4	11.75	10.2900
65.0	18.01	15.5100
74.40	25.83	21.9400
83.9	35.6	29.8900
94.6	49.05	40.6900
104.5	63.98	52.5500
116.3	85.13	69.1900
131.5	118.17	78.2400
150.0	167.93	-------
180.0	273.24	-------

Table 2.7. Carapace width and weight at age for male blue crabs, derived from empirical growth curve and carapace width-weight curve.

Age (yrs)	Width	Weight (gms)
0.083	12	-0.19
0.166	25	-2.66
0.250	28	-2.702
0.330	31	-2.546
0.420	34	-2.192
0.500	34	-2.192
0.580	34	-2.192
0.660	34	-2.192
0.750	34	-2.192
0.830	34	-2.192
0.910	44	0.418
1.000	55	5.83
1.080	65	13.06
1.160	75	22.49
1.250	80	28.03
1.330	84	32.86
1.410	89	39.39
1.500	89	39.39
1.580	89	39.39
1.660	89	39.39
1.740	89	39.39
1.830	89	39.39
1.910	101	57.30
2.000	112	76.50
2.080	125	102.64
2.160	125	102.64
2.240	130	113.68
2.320	132	118.25
2.410	135	125.27
2.500	135	125.27
2.580	135	125.27
2.660	135	125.27
2.750	135	125.27
2.830	135	125.27
2.920	145	150.10
3.000	155	177.13
3.080	162	197.36
3.160	162	197.36

Table 2.8. Carapace width and weight at age for female blue crabs, derived from empirical growth curve and carapace width-weight curve.

Age (yrs)	Width	Weight (gms)
0.083	12	-0.264
0.166	25	-0.290
0.250	28	0.04
0.330	31	0.496
0.420	34	1.078
0.500	34	1.078
0.580	34	1.078
0.660	34	1.078
0.750	34	1.078
0.830	34	1.078
0.910	45	4.290
1.000	55	8.680
1.080	65	14.470
1.160	65	14.470
1.250	70	17.890
1.330	74	20.878
1.410	79	24.928
1.500	79	24.928
1.580	79	24.928
1.660	79	24.928
1.740	79	24.928
1.830	79	24.928
1.910	91	36.076
2.000	103	49.240
2.080	115	64.420
2.160	115	64.420
2.240	118	68.530
2.320	121	72.766
2.410	124	77.128
2.500	124	77.128
2.580	124	77.128
2.660	124	77.128
2.750	124	77.128
2.830	124	77.128
2.920	134	92.578
3.000	145	111.190
3.080	155	129.580
3.160	155	129.580

Table 2.9. Daily average catch-per-pot for the size class containing the largest crab(s) captured, for early (5/23-7/09) and late (7/10-8/12) season sampling.

MALES AND FEMALES 5/23/87 - 7/09/87

SIZE CLASS	150-160		160-170		170-180		180-190		190-200	
	M	F	M	F	M	F	M	F	M	F
AVERAGE CATCH PER POT	.048	.053	.105	.154	.013	.054	.027	.013	.010	.050
		.067	.038	.061	.030	.027	.007	.009	.013	.016
		.303	.121	.087	.019	.049	.025	.020	.009	.015
		.316	.130	.019	.013	.021	.077	.010	.011	
			.050	.013	.038	.016	.037	.013	.009	
			.024	.024	.007	.074	.050	.029	.010	
			.171	.070	.071	.010	.020	.027	.025	
			.167	.030	.030	.013	.014	.010	.010	
			.106	.050	.040	.038	.078	.017		
			.122	.053	.050	.043	.008	.009		
			.070		.028	.024		.038		
			.077		.037	.015				
			.286		.032	.061				
			.259		.026	.098				
			.158		.029	.018				
			.308			.034				
			.577			.154				
						.143				
						.111				
						.074				
						.157				
						.088				
						.038				

MALES AND FEMALES 7/10/87 - 8/12/87

SIZE CLASS	150-160		160-170		170-180		180-190		190-200	
	M	F	M	F	M	F	M	F	M	F
AVERAGE CATCH PER POT		.098	.130	.028	.037	.036	.028	.033		
		.237	.357	.139	.054	.072	.034	.038		
				.019	.043	.023	.156	.026		
				.135	.231	.041	.014	.042		
				.048	.113	.156	.014	.021		
					.083	.028	.105	.071		
					.139	.053	.014	.013		
					.019	.055	.022			
					.028	.028	.011			
					.024	.050	.026			
					.026	.053				
					.026					
					.054					
					.048					
					.080					

Table 2.10. Von Bertalanffy growth parameters (L_{inf}, K), for male and female blue crabs, estimated from empirical data.

Sex	L_{inf}	Age(months)	K	$\bar{K}$
Male	174.25	2,14	0.40	
		14,26	0.70	0.83
		26,38	1.39	
Female	171.70	2,14	0.32	
		14,26	0.63	0.57
		26,38	0.75	

Table 2.11. Average carapace width of crabs captured in the commercial pot fishery sampling, by sample date.

Date	Mean Size Males	Mean Size Females
5-18	133	143
5-21	129	138
5-23	126	135
5-27	133	140
5-27	120	133
5-27	134	143
6-01	126	140
6-02	140	145
6-02	132	130
6-03	125	141
6-04	133	135
6-05	130	141
6-08	129	134
6-08	130	134
6-08	131	128
6-09	129	129
6-10	128	142
6-10	126	125
6-11	136	140
6-11	129	128
6-12	131	134
6-15	133	136
6-15	139	146
6-15	129	124
6-16	135	143
6-16	133	127
6-17	129	139
6-18	137	148
6-22	132	140
6-22	133	145
6-23	135	148
6-23	136	148
6-23	134	147
6-24	128	142
6-24	137	150
6-25	137	146
6-29	136	147
6-29	132	146
6-29	139	147

Table 2.11 (cont'd)

Date	Mean Size Males	Mean Size Females
6-30	129	143
6-30	131	148
7-01	135	149
7-01	137	150
7-02	133	138
7-06	133	151
7-07	131	147
7-07	137	150
7-07	133	140
7-08	134	148
7-08	130	144
7-09	139	146
7-10	136	145
7-14	136	143
7-15	149	154
7-15	146	150
7-16	138	140
7-17	129	144
7-20	141	146
7-20	143	155
7-21	129	138
7-21	142	152
7-22	135	141
7-27	138	126
7-29	142	142
7-29	133	137
7-30	139	139
7-30	134	145
8-03	133	136
8-04	139	138
8-05	130	133
8-05	137	143
8-06	143	141
8-10	133	134
8-11	141	138
8-12	143	143
8-12	133	142
8-13	138	130
8-17	140	140
8-19	139	151
8-24	133	147
8-29	134	148
9-12	132	150

Table 2.12. Fishing mortality (F=0.35) and natural mortality (M=0.30) for male Chesapeake Bay blue crabs; and the computation of equilibrium yield from 0.418 g of recruits at age 0.91 years (11 months).

AGE	WEIGHT	Ln(WT)	G	F	M	[G F M]	WEIGHT CHANGE FACTOR	WEIGHT OF STOCK	AVERAGE WEIGHT	YIELD
0.91	0.418	-0.8723						0.4180		
			2.637	0.0000	0.027	2.6050	13.5110		1.0370	0.0000
1.00	5.810	1.7630						5.6560		
			0.810	0.0000	0.024	0.7860	2.1946		9.0343	0.0000
1.08	13.060	2.5696						12.4127		
			0.540	0.0000	0.024	0.5160	1.6753		16.6019	0.0000
1.16	22.490	3.1131						20.2950		
			0.220	0.0115	0.027	0.1615	1.1753		22.6170	0.7126
1.25	28.030	3.3333						24.4198		
			0.160	0.0280	0.024	0.1080	1.1141		25.8335	0.7711
1.33	32.860	3.4923						27.2221		
			0.180	0.0280	0.024	0.1280	1.1366		29.0860	0.8186
1.41	39.390	3.6735						30.2630		
			0.000	0.0000	0.027	-0.0270	0.9734		30.5378	0.0000
1.50	39.390	3.6735						30.3207		
			0.000	0.0000	0.024	0.0240	0.9763		29.7636	0.0000
1.58	39.390	3.6735						29.6064		
			0.000	0.0000	0.024	-0.0240	0.9763		29.0500	0.0000
1.66	39.390	3.6735						28.7091		
			0.000	0.0000	0.026	-0.0260	0.9763		28.7688	0.0000
1.76	39.390	3.6735						28.0286		
			0.000	0.0000	0.027	-0.0270	0.9734		27.6551	0.0000
1.81	39.390	3.6735						27.2017		
			0.380	0.0280	0.024	0.3280	1.3882		32.5769	0.9122
1.91	57.100	4.0483						37.8222		
			0.290	0.0115	0.027	0.2315	1.2605		42.8049	1.3484
2.00	76.500	4.3373						47.7175		
			0.290	0.0280	0.024	0.2380	1.2687		54.1510	1.5162
2.08	102.640	4.6312						60.3666		
			0.000	0.0280	0.024	-0.0520	0.9493		59.0300	1.6528
2.16	102.650	4.6312						57.4958		
			0.1022	0.0280	0.024	0.0502	1.0514		58.9734	1.6513
2.24	113.680	4.7334						60.4511		
			0.0394	0.0280	0.024	0.0126	0.9875		60.0730	1.6870
2.32	118.250	4.7728						59.6959		
			0.5762	0.0115	0.027	-0.0008	0.9992		59.6701	1.8796
2.41	125.270	4.8305						59.6656		
			0.0000	0.0000	0.027	-0.0270	0.9734		58.8509	0.0000
2.50	125.270	4.8305						58.0565		
			0.0000	0.0000	0.024	-0.0240	0.9763		57.3687	0.0000
2.58	125.270	4.8305						56.6600		
			0.0000	0.0000	0.024	0.0240	0.9761		56.0080	0.0000
2.66	125.270	4.8305						55.3361		
			0.0000	0.0000	0.027	0.0270	0.9734		54.5990	0.0000
2.75	125.270	4.8305						53.8620		
			0.0000	0.0000	0.024	0.0240	0.9763		53.2235	0.0000
2.83	125.270	4.8305						52.5859		
			0.1808	0.0115	0.027	0.1221	1.1301		56.0108	1.7663
2.92	150.100	5.0113						59.4367		
			0.1656	0.0280	0.024	0.1136	1.1203		61.0267	1.7668
								66.6167		
3.00	177.130	5.1769							68.5405	1.9191
			0.1082	0.0280	0.024	0.0562	1.0578	70.4666		
3.08	197.360	5.2850							68.6792	1.9230
			0.0000	0.0280	0.024	0.0520	0.9493	66.8940		
3.16	197.360	5.2850								

Table 2.13. Fishing mortality (F=0.35) and natural mortality (M=0.60) for male Chesapeake Bay blue crabs; and the computation of equilibrium yield from 0.418 g of recruits at age 0.91 years (11 months).

AGE	WEIGHT	Ln(WT)	G	F	M	(G F M)	WEIGHT CHANGE FACTOR	WEIGHT OF STOCK	AVERAGE WEIGHT	YIELD
0.91	0.418	-0.8723	2.632	0.0000	0.0540	2.578	13.1708	0.418	2.9617	0.0000
1.00	5.830	1.7630	0.810	0.0000	0.0480	0.762	2.1426	5.505	8.6605	0.0000
1.09	11.060	2.5696	0.540	0.0000	0.0480	0.492	1.6356	11.796	15.5442	0.0000
1.16	22.490	3.1131	0.220	0.0315	0.0540	0.135	1.1440	19.293	20.6814	0.6515
1.25	28.030	3.3333	0.160	0.0280	0.0480	0.084	1.0876	22.070	23.0170	0.6430
1.33	32.860	3.4923	0.180	0.0280	0.0480	0.104	1.1096	24.004	25.1190	0.7009
1.41	39.390	3.6735	0.000	0.0000	0.0550	-0.054	0.9474	26.635	25.9359	0.0000
1.50	39.390	3.6735	0.000	0.0000	0.0480	-0.048	0.9531	25.235	24.6436	0.0000
1.58	39.390	3.6735	0.000	0.0000	0.0480	-0.048	0.9513	24.057	23.5804	0.0000
1.66	39.390	3.6735	0.000	0.0000	0.0480	-0.048	0.9513	22.975	22.3876	0.0000
1.74	39.390	3.6735	0.000	0.0000	0.0540	0.054	0.9474	21.850	21.2760	0.0000
1.83	39.390	3.6735	0.380	0.0280	0.0480	0.304	1.3553	20.702	26.3789	0.6826
1.91	57.300	4.0483	0.290	0.0315	0.0540	0.205	1.2269	28.056	31.2393	0.9840
2.00	76.500	4.3373	0.290	0.0280	0.0480	0.214	1.2386	36.472	38.5295	1.0786
2.08	102.640	4.6312	0.000	0.0280	0.0480	-0.260	0.9268	42.617	41.0764	1.1501
2.16	102.640	4.6312	0.1022	0.0280	0.0480	0.026	1.0265	39.516	40.0400	1.1211
2.24	113.680	4.7334	0.0394	0.0280	0.0480	-0.037	0.9641	40.564	39.8349	1.1155
2.32	118.250	4.7728	0.5767	0.0315	0.0540	-0.028	0.9726	39.106	38.5695	1.2150
2.41	125.270	4.8305	0.0000	0.0000	0.0560	-0.054	0.9474	38.013	37.0132	0.0000
2.50	125.270	4.8305	0.0000	0.0000	0.0480	-0.048	0.9531	36.034	35.1891	0.0000
2.58	125.270	4.8305	0.0000	0.0000	0.0480	0.048	0.9531	34.345	33.5397	0.0000
2.66	125.270	4.8305	0.0000	0.0000	0.0540	-0.054	0.9474	32.735	31.8766	0.0000
2.75	125.270	4.8305	0.0000	0.0000	0.0480	-0.048	0.9531	31.016	30.2873	0.0000
2.83	125.270	4.8305	0.1808	0.0315	0.0540	0.095	1.1000	29.561	31.0389	0.9222
2.92	150.100	5.0113	0.1656	0.0280	0.0480	0.090	1.0937	32.517	34.0409	0.95315
3.00	177.130	5.1769	0.1082	0.0280	0.0480	0.032	1.0327	35.565	36.1455	1.01210
3.08	197.360	5.2850	0.0000	0.0280	0.0480	-0.076	0.9268	36.727	35.1827	0.99022
3.16	197.360	5.2850						45.019		

Table 2.14. Fishing mortality (F=0.35) and natural mortality (M=1.0) for male Chesapeake Bay blue crabs; and the computation of equilibrium yield from 0.418 g of recruits at age 0.91 years (11 months).

AGE	WEIGHT	ln(WT)	G	F	M	(G-F-M)	WEIGHT CHANGE FACTOR	WEIGHT OF STOCK	AVERAGE WEIGHT	YIELD
0.91	0.418	-0.8723	2.637	0.0000	0.09	2.547	12.7100	0.4180	2.860	0.0000
1.00	5.830	1.7630	0.810	0.0000	0.08	0.730	2.0750	5.3110	8.166	0.0000
1.08	13.060	2.5696	0.540	0.0000	0.08	0.460	1.5840	11.0200	14.240	0.0000
1.16	22.490	3.1131	0.220	0.0315	0.09	0.099	1.1035	17.4560	18.359	0.5780
1.25	28.030	3.3333	0.160	0.0280	0.08	0.052	1.0530	19.2630	19.780	0.5500
1.33	32.860	3.4923	0.180	0.0280	0.08	0.072	1.0750	20.2910	21.048	0.5870
1.41	39.390	3.6735	0.000	0.0000	0.09	-0.090	0.9140	21.8060	20.868	0.0000
1.50	39.390	3.6735	0.000	0.0000	0.08	-0.080	0.9230	19.9290	19.162	0.0000
1.58	39.390	3.6735	0.000	0.0000	0.08	-0.080	0.9230	18.3900	17.680	0.0000
1.66	39.390	3.6735	0.000	0.0000	0.08	-0.080	0.9230	16.9740	16.321	0.0000
1.74	39.390	3.6735	0.000	0.0000	0.09	-0.090	0.9140	15.6670	14.994	0.0000
1.83	39.390	3.6735	0.380	0.0280	0.08	0.272	1.3100	16.3200	16.540	0.4630
1.91	57.300	4.0483	0.290	0.0315	0.09	0.169	1.1840	18.7600	20.490	0.6450
2.00	76.500	4.3373	0.290	0.0280	0.08	0.182	1.1996	22.2100	24.427	0.6840
2.08	102.640	4.6312	0.000	0.0280	0.08	-0.108	0.8980	26.6430	25.284	0.7080
2.16	102.640	4.6312	0.1092	0.0280	0.08	-0.006	0.9942	23.9250	23.855	0.6680
2.24	111.680	4.7156	0.0396	0.0280	0.09	-0.069	0.9337	23.7858	22.997	0.6439
2.32	118.250	4.7728	0.0567	0.0315	0.09	-0.066	0.9382	22.7090	21.522	0.6780
2.41	125.270	4.8305	0.0000	0.0000	0.09	-0.090	0.9139	20.8157	19.939	0.0000
2.50	125.270	4.8305	0.0000	0.0000	0.08	-0.080	0.9211	19.0424	18.310	0.0000
2.58	125.270	4.8305	0.0000	0.0000	0.08	-0.080	0.9231	17.5784	16.903	0.0000
2.66	125.270	4.8305	0.0000	0.0000	0.09	-0.090	0.9139	16.2270	15.523	0.0000
2.75	125.270	4.8305	0.0000	0.0000	0.08	-0.080	0.9231	14.8303	14.260	0.0000
2.83	125.270	4.8305	0.1808	0.0315	0.09	0.059	1.0611	13.6902	14.109	0.4442
2.92	150.100	5.0113	0.1656	0.0280	0.08	0.058	1.0593	14.5770	14.958	0.4188
3.00	177.130	5.1769	0.1082	0.0280	0.08	0.000	1.0002	15.3880	15.389	0.4309
3.08	197.360	5.2850	0.0000	0.0280	0.08	-0.108	0.8976	15.3903	14.603	0.4089
3.16	197.360	5.2850						11.8148		

Table 2.15. Recruitment index derived from Smith Island scrape fishery data and total reported landings in the Maryland and Virginia (hard and soft) crab fisheries 1948-1972.

Year	Catch	Recruits (crabs<75 mm)
1948	67946	517
1949	67626	1099
1950	80046	1393
1951	70777	632
1952	64831	1197
1953	63184	612
1954	54743	533
1955	45128	no data
1956	50598	no data
1957	58351	375
1958	49462	454
1959	45549	691
1960	70716	310
1961	74894	362
1962	86571	158
1963	66129	313
1964	78608	190
1965	86334	266
1966	97016	627
1967	82815	419
1968	55994	116
1969	60876	886
1970	69841	440
1971	76105	652
1972	74469	703

Appendix B

Yield Matrices

Equilibrium yield matrix for male Chesapeake Bay blue crabs with natural mortality rate (M) of 0.30, and varying age at first capture and fishing mortality rate (F).

AGE	F=0.35	F=0.70	F=1.05	F=1.40	F=1.75	F=3.01
0.91	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
1.50	0.28090E+01	0.55424E+01	0.82034E+01	0.10795E+02	0.13320E+02	0.21902E+02
1.91	0.54573E+01	0.10615E+02	0.15491E+02	0.20103E+02	0.24467E+02	0.38348E+02
2.00	0.77446E+01	0.14842E+02	0.21347E+02	0.27310E+02	0.32778E+02	0.48984E+02
2.08	0.98670E+01	0.18583E+02	0.26280E+02	0.33075E+02	0.39072E+02	0.55383E+02
2.16	0.98670E+01	0.18583E+02	0.26280E+02	0.33075E+02	0.39072E+02	0.55383E+02
2.24	0.98670E+01	0.18583E+02	0.26280E+02	0.33075E+02	0.39072E+02	0.55383E+02
2.32	0.98670E+01	0.18583E+02	0.26280E+02	0.33075E+02	0.39072E+02	0.55383E+02
2.41	0.98670E+01	0.18583E+02	0.26280E+02	0.33075E+02	0.39072E+02	0.55383E+02
2.50	0.98670E+01	0.18583E+02	0.26280E+02	0.33075E+02	0.39072E+02	0.55383E+02
2.58	0.12000E+02	0.22251E+02	0.31004E+02	0.38476E+02	0.44852E+02	0.60984E+02
2.66	0.13791E+02	0.25226E+02	0.34701E+02	0.42549E+02	0.49046E+02	0.64448E+02
2.75	0.15436E+02	0.27846E+02	0.37814E+02	0.45810E+02	0.52219E+02	0.66368E+02
2.83	0.16982E+02	0.30221E+02	0.40526E+02	0.48535E+02	0.54748E+02	0.67541E+02
2.92	0.18269E+02	0.32032E+02	0.42368E+02	0.50099E+02	0.55854E+02	0.66567E+02
3.00	0.19213E+02	0.33045E+02	0.42925E+02	0.49906E+02	0.54769E+02	0.62218E+02
3.08	0.19213E+02	0.33045E+02	0.42925E+02	0.49906E+02	0.54769E+02	0.62218E+02
3.16	0.19213E+02	0.33045E+02	0.42925E+02	0.49906E+02	0.54769E+02	0.62218E+02

Equilibrium yield matrix for male Chesapeake Bay blue crabs with natural mortality rate (M) of 0.40 and varying age at first capture and fishing mortality rate (F).

AGE	F=0.35	F=0.70	F=1.05	F=1.40	F=1.75	F=3.01
0.91	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
1.50	0.22523E+01	0.44442E+01	0.65783E+01	0.86570E+01	0.10683E+02	0.17569E+02
1.91	0.43928E+01	0.85453E+01	0.12472E+02	0.16187E+02	0.19703E+02	0.30893E+02
2.00	0.62571E+01	0.11993E+02	0.17253E+02	0.22078E+02	0.26503E+02	0.39635E+02
2.08	0.80037E+01	0.15079E+02	0.21332E+02	0.26856E+02	0.31737E+02	0.45041E+02
2.16	0.80037E+01	0.15079E+02	0.21332E+02	0.26856E+02	0.31737E+02	0.45041E+02
2.24	0.80037E+01	0.15079E+02	0.21332E+02	0.26856E+02	0.31737E+02	0.45041E+02
2.32	0.80037E+01	0.15079E+02	0.21332E+02	0.26856E+02	0.31737E+02	0.45041E+02
2.41	0.80037E+01	0.15079E+02	0.21332E+02	0.26856E+02	0.31737E+02	0.45041E+02
2.50	0.80037E+01	0.15079E+02	0.21332E+02	0.26856E+02	0.31737E+02	0.45041E+02
2.58	0.98643E+01	0.18311E+02	0.25542E+02	0.31734E+02	0.37035E+02	0.50568E+02
2.66	0.11443E+02	0.20964E+02	0.28887E+02	0.35479E+02	0.40966E+02	0.54153E+02
2.75	0.12907E+02	0.23334E+02	0.31753E+02	0.38550E+02	0.44035E+02	0.56379E+02
2.83	0.14298E+02	0.25511E+02	0.34298E+02	0.41182E+02	0.46571E+02	0.57944E+02
2.92	0.15471E+02	0.27208E+02	0.36095E+02	0.42807E+02	0.47861E+02	0.57583E+02
3.00	0.16351E+02	0.28220E+02	0.36781E+02	0.42906E+02	0.47239E+02	0.54231E+02
3.08	0.16351E+02	0.28220E+02	0.36781E+02	0.42906E+02	0.47239E+02	0.54231E+02
3.16	0.16351E+02	0.28220E+02	0.36781E+02	0.42906E+02	0.47239E+02	0.54231E+02

Equilibrium yield matrix for male Chesapeake Bay blue crabs with natural mortality rate (M) of 0.50 and varying age at first capture and fishing mortality rate (F).

AGE	F-0.35	F-0.70	F-1.05	F-1.40	F-1.75	F-3.01
0.91	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
1.50	0.18059E+01	0.35636E+01	0.52752E+01	0.69425E+01	0.85674E+01	0.14093E+02
1.91	0.35360E+01	0.68794E+01	0.10042E+02	0.13034E+02	0.15867E+02	0.24888E+02
2.00	0.50556E+01	0.96924E+01	0.13946E+02	0.17849E+02	0.21431E+02	0.32073E+02
2.08	0.64928E+01	0.12237E+02	0.17317E+02	0.21809E+02	0.25782E+02	0.36634E+02
2.16	0.64928E+01	0.12237E+02	0.17317E+02	0.21809E+02	0.25782E+02	0.36634E+02
2.24	0.64928E+01	0.12237E+02	0.17317E+02	0.21809E+02	0.25782E+02	0.36634E+02
2.32	0.64928E+01	0.12237E+02	0.17317E+02	0.21809E+02	0.25782E+02	0.36634E+02
2.41	0.64928E+01	0.12237E+02	0.17317E+02	0.21809E+02	0.25782E+02	0.36634E+02
2.50	0.64928E+01	0.12237E+02	0.17317E+02	0.21809E+02	0.25782E+02	0.36634E+02
2.58	0.81148E+01	0.15080E+02	0.21060E+02	0.26195E+02	0.30607E+02	0.41968E+02
2.66	0.95047E+01	0.17443E+02	0.24075E+02	0.29619E+02	0.34256E+02	0.45555E+02
2.75	0.10807E+02	0.19579E+02	0.26700E+02	0.32484E+02	0.37184E+02	0.47953E+02
2.83	0.12057E+02	0.21568E+02	0.29072E+02	0.34995E+02	0.39673E+02	0.49775E+02
2.92	0.13124E+02	0.23149E+02	0.30801E+02	0.36634E+02	0.41075E+02	0.49875E+02
3.00	0.13941E+02	0.24143E+02	0.31573E+02	0.36950E+02	0.40810E+02	0.47329E+02
3.08	0.13941E+02	0.24143E+02	0.31573E+02	0.36950E+02	0.40810E+02	0.47329E+02
3.16	0.13941E+02	0.24143E+02	0.31573E+02	0.36950E+02	0.40810E+02	0.47329E+02

Equilibrium yield matrix for male Chesapeake Bay blue crabs with natural mortality rate (M) of 0.60 and varying age at first capture and fishing mortality rate (F).

AGE	F-0.35	F-0.70	F-1.05	F-1.40	F-1.75	F-3.01
0.91	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
1.50	0.14480E+01	0.28576E+01	0.42303E+01	0.55676E+01	0.68711E+01	0.11305E+02
1.91	0.28464E+01	0.55384E+01	0.80853E+01	0.10496E+02	0.12778E+02	0.20051E+02
2.00	0.40851E+01	0.78333E+01	0.11273E+02	0.14431E+02	0.17331E+02	0.25954E+02
2.08	0.52677E+01	0.99311E+01	0.14059E+02	0.17712E+02	0.20946E+02	0.29800E+02
2.16	0.52677E+01	0.99311E+01	0.14059E+02	0.17712E+02	0.20946E+02	0.29800E+02
2.24	0.52677E+01	0.99311E+01	0.14059E+02	0.17712E+02	0.20946E+02	0.29800E+02
2.32	0.52677E+01	0.99311E+01	0.14059E+02	0.17712E+02	0.20946E+02	0.29800E+02
2.41	0.52677E+01	0.99311E+01	0.14059E+02	0.17712E+02	0.20946E+02	0.29800E+02
2.50	0.52677E+01	0.99311E+01	0.14059E+02	0.17712E+02	0.20946E+02	0.29800E+02
2.58	0.66809E+01	0.12430E+02	0.17378E+02	0.21641E+02	0.25316E+02	0.34863E+02
2.66	0.79038E+01	0.14529E+02	0.20087E+02	0.24755E+02	0.28679E+02	0.38367E+02
2.75	0.90611E+01	0.16451E+02	0.22482E+02	0.27410E+02	0.31441E+02	0.40837E+02
2.83	0.10183E+02	0.18263E+02	0.24679E+02	0.29781E+02	0.33845E+02	0.42811E+02
2.92	0.11151E+02	0.19728E+02	0.26326E+02	0.31400E+02	0.35303E+02	0.43252E+02
3.00	0.11908E+02	0.20691E+02	0.27148E+02	0.31873E+02	0.35311E+02	0.41357E+02
3.08	0.11908E+02	0.20691E+02	0.27148E+02	0.31873E+02	0.35311E+02	0.41357E+02
3.16	0.11908E+02	0.20691E+02	0.27148E+02	0.31873E+02	0.35311E+02	0.41357E+02

Equilibrium yield matrix for male Chesapeake Bay blue crabs with natural mortality rate (M) of 0.70 and varying age at first capture and fishing mortality rate (F).

AGE	F-0.35	F-0.70	F-1.05	F-1.40	F-1.75	F-3.01
0.91	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
1.50	0.11611E+01	0.22915E+01	0.33924E+01	0.44651E+01	0.55108E+01	0.90686E+01
1.91	0.22914E+01	0.44590E+01	0.65102E+01	0.84520E+01	0.10291E+02	0.16155E+02
2.00	0.33011E+01	0.63311E+01	0.91131E+01	0.11668E+02	0.14015E+02	0.21004E+02
2.08	0.42742E+01	0.80608E+01	0.11415E+02	0.14387E+02	0.17019E+02	0.24242E+02
2.16	0.42742E+01	0.80608E+01	0.11415E+02	0.14387E+02	0.17019E+02	0.24242E+02
2.24	0.42742E+01	0.80608E+01	0.11415E+02	0.14387E+02	0.17019E+02	0.24242E+02
2.32	0.42742E+01	0.80608E+01	0.11415E+02	0.14387E+02	0.17019E+02	0.24242E+02
2.41	0.42742E+01	0.80608E+01	0.11415E+02	0.14387E+02	0.17019E+02	0.24242E+02
2.50	0.42742E+01	0.80608E+01	0.11415E+02	0.14387E+02	0.17019E+02	0.24242E+02
2.58	0.55048E+01	0.10253E+02	0.14353E+02	0.17895E+02	0.20958E+02	0.28987E+02
2.66	0.65801E+01	0.12116E+02	0.16780E+02	0.20714E+02	0.24039E+02	0.32350E+02
2.75	0.76074E+01	0.13841E+02	0.18956E+02	0.23159E+02	0.26620E+02	0.34819E+02
2.83	0.86133E+01	0.15487E+02	0.20981E+02	0.25381E+02	0.28914E+02	0.36865E+02
2.92	0.94909E+01	0.16840E+02	0.22536E+02	0.26955E+02	0.30387E+02	0.37553E+02
3.00	0.10189E+02	0.17763E+02	0.23382E+02	0.27538E+02	0.30599E+02	0.36180E+02
3.08	0.10189E+02	0.17763E+02	0.23382E+02	0.27538E+02	0.30599E+02	0.36180E+02
3.16	0.10189E+02	0.17763E+02	0.23382E+02	0.27538E+02	0.30599E+02	0.36180E+02

Equilibrium yield matrix for male Chesapeake Bay blue crabs with natural mortality rate (M) of 1.00 and varying age at first capture and fishing mortality rate (F).

AGE	F-0.35	F-0.70	F-1.05	F-1.40	F-1.75	F-3.01
0.91	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
1.50	0.59866E+00	0.11817E+01	0.17497E+01	0.23034E+01	0.28433E+01	0.46817E+01
1.91	0.11956E+01	0.23274E+01	0.33991E+01	0.44144E+01	0.53767E+01	0.84501E+01
2.00	0.17424E+01	0.33438E+01	0.48159E+01	0.61698E+01	0.74154E+01	0.11137E+02
2.08	0.22846E+01	0.43130E+01	0.61140E+01	0.77135E+01	0.91341E+01	0.13059E+02
2.16	0.22846E+01	0.43130E+01	0.61140E+01	0.77135E+01	0.91341E+01	0.13059E+02
2.24	0.22846E+01	0.43130E+01	0.61140E+01	0.77135E+01	0.91341E+01	0.13059E+02
2.32	0.22846E+01	0.43130E+01	0.61140E+01	0.77135E+01	0.91341E+01	0.13059E+02
2.41	0.22846E+01	0.43130E+01	0.61140E+01	0.77135E+01	0.91341E+01	0.13059E+02
2.50	0.22846E+01	0.43130E+01	0.61140E+01	0.77135E+01	0.91341E+01	0.13059E+02
2.58	0.30950E+01	0.57858E+01	0.81284E+01	0.10172E+02	0.11957E+02	0.16758E+02
2.66	0.38235E+01	0.70768E+01	0.98512E+01	0.12223E+02	0.14256E+02	0.19524E+02
2.75	0.45389E+01	0.83108E+01	0.11454E+02	0.14080E+02	0.16282E+02	0.21732E+02
2.83	0.52599E+01	0.95287E+01	0.13004E+02	0.15844E+02	0.18174E+02	0.23699E+02
2.92	0.59084E+01	0.10573E+02	0.14267E+02	0.17201E+02	0.19539E+02	0.24739E+02
3.00	0.64498E+01	0.11352E+02	0.15082E+02	0.17921E+02	0.20082E+02	0.24381E+02
3.08	0.64498E+01	0.11352E+02	0.15082E+02	0.17921E+02	0.20082E+02	0.24381E+02
3.16	0.64498E+01	0.11352E+02	0.15082E+02	0.17921E+02	0.20082E+02	0.24381E+02

Equilibrium yield matrix for female Chesapeake Bay blue crabs with natural mortality rate (M) of 0.30 and varying age at first capture and fishing mortality rate (F).

AGE	F-0.35	F-0.70	F-1.05	F-1.40	F-1.75	F-3.0
0.25	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.42	0.15130E+01	0.29853E+01	0.44186E+01	0.58145E+01	0.71746E+01	0.11797E+02
0.91	0.29081E+01	0.56548E+01	0.82500E+01	0.10703E+02	0.13022E+02	0.20386E+02
1.50	0.40730E+01	0.78005E+01	0.11212E+02	0.14336E+02	0.17195E+02	0.25638E+02
1.91	0.51411E+01	0.96738E+01	0.13668E+02	0.17187E+02	0.20286E+02	0.28665E+02
2.00	0.59934E+01	0.11109E+02	0.15471E+02	0.19187E+02	0.22351E+02	0.30283E+02
2.08	0.69531E+01	0.12687E+02	0.17411E+02	0.21297E+02	0.24492E+02	0.31930E+02
2.16	0.78074E+01	0.14061E+02	0.19063E+02	0.23062E+02	0.26254E+02	0.33255E+02
2.24	0.6635E+02	0.15409E+02	0.20657E+02	0.24737E+02	0.27906E+02	0.34495E+02
2.32	0.96296E+01	0.16901E+02	0.22389E+02	0.26531E+02	0.29659E+02	0.35831E+02
2.41	0.10563E+02	0.18294E+02	0.23952E+02	0.28095E+02	0.31130E+02	0.36792E+02
2.50	0.11331E+02	0.19389E+02	0.25117E+02	0.29188E+02	0.32084E+02	0.37161E+02
2.58	0.12041E+02	0.20349E+02	0.26076E+02	0.30018E+02	0.32731E+02	0.37152E+02
2.66	0.12724E+02	0.21244E+02	0.26940E+02	0.30740E+02	0.33269E+02	0.37118E+02
2.75	0.13286E+02	0.21888E+02	0.27429E+02	0.30977E+02	0.33226E+02	0.36203E+02
2.83	0.13664E+02	0.22104E+02	0.27244E+02	0.30308E+02	0.32070E+02	0.33590E+02
2.92	0.13664E+02	0.22104E+02	0.27244E+02	0.30308E+02	0.32070E+02	0.33590E+02
3.00	0.13664E+02	0.22104E+02	0.27244E+02	0.30308E+02	0.32070E+02	0.33590E+02
3.08	0.13664E+02	0.22104E+02	0.27244E+02	0.30308E+02	0.32070E+02	0.33590E+02
3.16	0.13664E+02	0.22104E+02	0.27244E+02	0.30308E+02	0.32070E+02	0.33590E+02

Equilibrium yield matrix for female Chesapeake Bay blue crabs with natural mortality rate (M) of 0.40 and varying age at first capture and fishing mortality rate (F).

AGE	F-0.35	F-0.70	F-1.05	F-1.40	F-1.75	F-3.0
0.25	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.42	0.11356E+01	0.22409E+01	0.33169E+01	0.43651E+01	0.53864E+01	0.88586E+01
0.91	0.21912E+01	0.42612E+01	0.62174E+01	0.80668E+01	0.98158E+01	0.15372E+02
1.50	0.30800E+01	0.58999E+01	0.84821E+01	0.10847E+02	0.13013E+02	0.19416E+02
1.91	0.39029E+01	0.73464E+01	0.10384E+02	0.13061E+02	0.15421E+02	0.21818E+02
2.00	0.45665E+01	0.84683E+01	0.11800E+02	0.14642E+02	0.17065E+02	0.23166E+02
2.08	0.53711E+01	0.97170E+01	0.13345E+02	0.16338E+02	0.18804E+02	0.24584E+02
2.16	0.59998E+01	0.10817E+02	0.14682E+02	0.17780E+02	0.20263E+02	0.25763E+02
2.24	0.66866E+01	0.11910E+02	0.15989E+02	0.19173E+02	0.21659E+02	0.26899E+02
2.32	0.74698E+01	0.13134E+02	0.17431E+02	0.20693E+02	0.23172E+02	0.28158E+02
2.41	0.82351E+01	0.14295E+02	0.18759E+02	0.22051E+02	0.24486E+02	0.29141E+02
2.50	0.88733E+01	0.15224E+02	0.19774E+02	0.23038E+02	0.25386E+02	0.29636E+02
2.58	0.94693E+01	0.16054E+02	0.20635E+02	0.23825E+02	0.26052E+02	0.29832E+02
2.66	0.10050E+02	0.16841E+02	0.21432E+02	0.24538E+02	0.26643E+02	0.30018E+02
2.75	0.10537E+02	0.17429E+02	0.21929E+02	0.24859E+02	0.26759E+02	0.29470E+02
2.83	0.10876E+02	0.17673E+02	0.21880E+02	0.24444E+02	0.25967E+02	0.27518E+02
2.92	0.10876E+02	0.17673E+02	0.21880E+02	0.24444E+02	0.25967E+02	0.27518E+02
3.00	0.10876E+02	0.17673E+02	0.21880E+02	0.24444E+02	0.25967E+02	0.27518E+02
3.08	0.10876E+02	0.17673E+02	0.21880E+02	0.24444E+02	0.25967E+02	0.27518E+02
3.16	0.10876E+02	0.17673E+02	0.21880E+02	0.24444E+02	0.25967E+02	0.27518E+02

Equilibrium yield matrix for female Chesapeake Bay blue crabs with natural mortality rate (M) of 0.50 and varying age at first capture and fishing mortality rate (F).

AGE	F-0.35	F-0.70	F-1.05	F-1.40	F-1.75	F-3.0
0.25	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.42	0.85242E+00	0.16821E+01	0.24900E+01	0.32770E+01	0.40440E+01	0.66521E+01
0.91	0.16510E+01	0.32111E+01	0.46857E+01	0.60801E+01	0.73992E+01	0.11592E+02
1.50	0.23292E+01	0.44626E+01	0.64170E+01	0.82077E+01	0.98488E+01	0.14705E+02
1.91	0.29632E+01	0.55795E+01	0.78889E+01	0.99268E+01	0.11725E+02	0.16608E+02
2.00	0.34798E+01	0.64565E+01	0.90013E+01	0.11175E+02	0.13032E+02	0.17724E+02
2.08	0.40732E+01	0.74439E+01	0.10232E+02	0.12536E+02	0.14440E+02	0.18931E+02
2.16	0.46122E+01	0.83241E+01	0.11310E+02	0.13712E+02	0.15644E+02	0.19964E+02
2.24	0.51629E+01	0.92088E+01	0.12380E+02	0.14866E+02	0.16817E+02	0.20983E+02
2.32	0.57975E+01	0.10212E+02	0.13578E+02	0.16147E+02	0.18113E+02	0.22138E+02
2.41	0.64245E+01	0.11178E+02	0.14701E+02	0.17319E+02	0.19272E+02	0.23092E+02
2.50	0.69538E+01	0.11963E+02	0.15578E+02	0.18197E+02	0.20100E+02	0.23647E+02
2.58	0.74537E+01	0.12676E+02	0.16343E+02	0.18925E+02	0.20752E+02	0.23969E+02
2.66	0.79466E+01	0.13364E+02	0.17067E+02	0.19606E+02	0.21355E+02	0.24292E+02
2.75	0.83658E+01	0.13894E+02	0.17551E+02	0.19970E+02	0.21572E+02	0.24006E+02
2.83	0.86674E+01	0.14149E+02	0.17594E+02	0.19737E+02	0.21049E+02	0.22561E+02
2.92	0.86674E+01	0.14149E+02	0.17594E+02	0.19737E+02	0.21049E+02	0.22561E+02
3.00	0.86674E+01	0.14149E+02	0.17594E+02	0.19737E+02	0.21049E+02	0.22561E+02
3.08	0.86674E+01	0.14149E+02	0.17594E+02	0.19737E+02	0.21049E+02	0.22561E+02
3.16	0.86674E+01	0.14149E+02	0.17594E+02	0.19737E+02	0.21049E+02	0.22561E+02

Equilibrium yield matrix for female Chesapeake Bay blue crabs with natural mortality rate (M) of 0.60 and varying age at first capture and fishing mortality rate (F).

AGE	F=0.35	F=0.70	F=1.05	F=1.40	F=1.75	F=3.0
0.25	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.42	0.85242E+00	0.16821E+01	0.24900E+01	0.32770E+01	0.40440E+01	0.66521E+01
0.91	0.16510E+01	0.32111E+01	0.46857E+01	0.60801E+01	0.73992E+01	0.11592E+02
1.50	0.23292E+01	0.44626E+01	0.64170E+01	0.82077E+01	0.98488E+01	0.14705E+02
1.91	0.29632E+01	0.55795E+01	0.78889E+01	0.99268E+01	0.11725E+02	0.16608E+02
2.00	0.34798E+01	0.64565E+01	0.90013E+01	0.11175E+02	0.13032E+02	0.17724E+02
2.08	0.40732E+01	0.74439E+01	0.10232E+02	0.12536E+02	0.14440E+02	0.18931E+02
2.16	0.46122E+01	0.83241E+01	0.11310E+02	0.13712E+02	0.15644E+02	0.19964E+02
2.24	0.51629E+01	0.92088E+01	0.12380E+02	0.14866E+02	0.16817E+02	0.20983E+02
2.32	0.57975E+01	0.10212E+02	0.13578E+02	0.16147E+02	0.18113E+02	0.22138E+02
2.41	0.64245E+01	0.11178E+02	0.14701E+02	0.17319E+02	0.19272E+02	0.23092E+02
2.50	0.69538E+01	0.11963E+02	0.15578E+02	0.18197E+02	0.20100E+02	0.23647E+02
2.58	0.74537E+01	0.12676E+02	0.16343E+02	0.18925E+02	0.20752E+02	0.23969E+02
2.66	0.79466E+01	0.13364E+02	0.17067E+02	0.19606E+02	0.21355E+02	0.24292E+02
2.75	0.83658E+01	0.13894E+02	0.17551E+02	0.19970E+02	0.21572E+02	0.24006E+02
2.83	0.86674E+01	0.14149E+02	0.17594E+02	0.19737E+02	0.21049E+02	0.22561E+02
2.92	0.86674E+01	0.14149E+02	0.17594E+02	0.19737E+02	0.21049E+02	0.22561E+02
3.00	0.86674E+01	0.14149E+02	0.17594E+02	0.19737E+02	0.21049E+02	0.22561E+02
3.08	0.86674E+01	0.14149E+02	0.17594E+02	0.19737E+02	0.21049E+02	0.22561E+02
3.16	0.86674E+01	0.14149E+02	0.17594E+02	0.19737E+02	0.21049E+02	0.22561E+02

Equilibrium yield matrix for female Chesapeake Bay blue crabs with natural mortality rate (M) of 0.60 and varying age at first capture and fishing mortality rate (F).

AGE	F-0.35	F-0.70	F-1.05	F-1.40	F-1.75	F-3.0
0.25	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.42	0.63985E+00	0.12627E+01	0.18693E+01	0.24602E+01	0.30362E+01	0.49953E+01
0.91	0.12440E+01	0.24198E+01	0.35315E+01	0.45829E+01	0.55778E+01	0.87420E+01
1.50	0.17615E+01	0.33757E+01	0.48550E+01	0.62110E+01	0.74543E+01	0.11138E+02
1.91	0.22500E+01	0.42380E+01	0.59942E+01	0.75452E+01	0.89147E+01	0.12644E+02
2.00	0.26521E+01	0.49233E+01	0.68675E+01	0.85307E+01	0.99530E+01	0.13562E+02
2.08	0.31186E+01	0.57039E+01	0.78463E+01	0.96210E+01	0.11091E+02	0.14582E+02
2.16	0.35465E+01	0.64078E+01	0.87160E+01	0.10578E+02	0.12081E+02	0.15475E+02
2.24	0.39880E+01	0.71232E+01	0.95895E+01	0.11531E+02	0.13062E+02	0.16374E+02
2.32	0.45019E+01	0.79445E+01	0.10581E+02	0.12606E+02	0.14166E+02	0.17413E+02
2.41	0.50153E+01	0.87456E+01	0.11528E+02	0.13610E+02	0.15176E+02	0.18307E+02
2.50	0.54537E+01	0.94071E+01	0.12282E+02	0.14383E+02	0.15926E+02	0.18878E+02
2.58	0.58725E+01	0.10018E+02	0.12955E+02	0.15045E+02	0.16543E+02	0.19269E+02
2.66	0.62899E+01	0.10616E+02	0.13604E+02	0.15680E+02	0.17132E+02	0.19671E+02
2.75	0.66500E+01	0.11089E+02	0.14062E+02	0.16059E+02	0.17407E+02	0.19569E+02
2.83	0.69166E+01	0.11342E+02	0.14164E+02	0.15955E+02	0.17079E+02	0.18510E+02
2.92	0.69166E+01	0.11342E+02	0.14164E+02	0.15955E+02	0.17079E+02	0.18510E+02
3.00	0.69166E+01	0.11342E+02	0.14164E+02	0.15955E+02	0.17079E+02	0.18510E+02
3.08	0.69166E+01	0.11342E+02	0.14164E+02	0.15955E+02	0.17079E+02	0.18510E+02
3.16	0.69166E+01	0.11342E+02	0.14164E+02	0.15955E+02	0.17079E+02	0.18510E+02

Equilibrium yield matrix for female Chesapeake Bay blue crabs with natural mortality rate (M) of 0.70 and varying age at first capture and fishing mortality rate (F).

AGE	F-0.35	F-0.70	F-1.05	F-1.40	F-1.75	F-3.0
0.25	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.42	0.48029E+00	0.94787E+00	0.14033E+01	0.18470E+01	0.22796E+01	0.37512E+01
0.91	0.93742E+00	0.18236E+01	0.26616E+01	0.34545E+01	0.42048E+01	0.65927E+01
1.50	0.13323E+01	0.25536E+01	0.36734E+01	0.47004E+01	0.56423E+01	0.84365E+01
1.91	0.17086E+01	0.32193E+01	0.45550E+01	0.57356E+01	0.67790E+01	0.96265E+01
2.00	0.20216E+01	0.37548E+01	0.52403E+01	0.65129E+01	0.76028E+01	0.10379E+02
2.08	0.23882E+01	0.43716E+01	0.60184E+01	0.73856E+01	0.85206E+01	0.11234E+02
2.16	0.27280E+01	0.49341E+01	0.67188E+01	0.81631E+01	0.93329E+01	0.11999E+02
2.24	0.30817E+01	0.55122E+01	0.74310E+01	0.89481E+01	0.10150E+02	0.12782E+02
2.32	0.34976E+01	0.61835E+01	0.82508E+01	0.98468E+01	0.11084E+02	0.13701E+02
2.41	0.39178E+01	0.68471E+01	0.90451E+01	0.10702E+02	0.11958E+02	0.14521E+02
2.50	0.42804E+01	0.74030E+01	0.96909E+01	0.11376E+02	0.12627E+02	0.15079E+02
2.58	0.46308E+01	0.79241E+01	0.10278E+02	0.11971E+02	0.13197E+02	0.15500E+02
2.66	0.49838E+01	0.84415E+01	0.10855E+02	0.12551E+02	0.13755E+02	0.15938E+02
2.75	0.52922E+01	0.88605E+01	0.11279E+02	0.12927E+02	0.14060E+02	0.15962E+02
2.83	0.55266E+01	0.91029E+01	0.11417E+02	0.12911E+02	0.13873E+02	0.15197E+02
2.92	0.55266E+01	0.91029E+01	0.11417E+02	0.12911E+02	0.13873E+02	0.15197E+02
3.00	0.55266E+01	0.91029E+01	0.11417E+02	0.12911E+02	0.13873E+02	0.15197E+02
3.08	0.55266E+01	0.91029E+01	0.11417E+02	0.12911E+02	0.13873E+02	0.15197E+02
3.16	0.55266E+01	0.91029E+01	0.11417E+02	0.12911E+02	0.13873E+02	0.15197E+02

Equilibrium yield matrix for female Chesapeake Bay blue crabs with natural mortality rate (M) of 1.00 and varying age at first capture and fishing mortality rate (F).

AGE	F-0.35	F-0.70	F-1.05	F-1.40	F-1.75	F-3.0
0.25	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.42	0.20315E+00	0.40100E+00	0.59376E+00	0.78164E+00	0.96486E+00	0.15887E+01
0.91	0.40116E+00	0.78064E+00	0.11398E+01	0.14797E+01	0.18017E+01	0.28282E+01
1.50	0.57660E+00	0.11058E+01	0.15917E+01	0.20379E+01	0.24477E+01	0.36675E+01
1.91	0.74862E+00	0.14120E+01	0.19999E+01	0.25209E+01	0.29826E+01	0.42511E+01
2.00	0.89614E+00	0.16671E+01	0.23304E+01	0.29009E+01	0.33917E+01	0.46567E+01
2.08	0.10741E+01	0.19708E+01	0.27197E+01	0.33456E+01	0.38689E+01	0.51440E+01
2.16	0.12438E+01	0.22570E+01	0.30833E+01	0.37581E+01	0.43103E+01	0.56022E+01
2.24	0.14254E+01	0.25604E+01	0.34661E+01	0.41909E+01	0.47729E+01	0.60923E+01
2.32	0.16454E+01	0.29247E+01	0.39233E+01	0.47066E+01	0.53248E+01	0.66911E+01
2.41	0.18747E+01	0.32984E+01	0.43857E+01	0.52219E+01	0.58703E+01	0.72659E+01
2.50	0.20791E+01	0.36242E+01	0.47804E+01	0.56529E+01	0.63179E+01	0.77078E+01
2.58	0.22828E+01	0.39419E+01	0.51577E+01	0.60572E+01	0.67304E+01	0.80933E+01
2.66	0.24943E+01	0.42691E+01	0.55445E+01	0.64717E+01	0.71550E+01	0.85083E+01
2.75	0.26859E+01	0.45498E+01	0.58562E+01	0.67825E+01	0.74481E+01	0.86957E+01
2.83	0.28412E+01	0.47411E+01	0.60201E+01	0.68870E+01	0.74785E+01	0.84452E+01
2.92	0.28412E+01	0.47411E+01	0.60201E+01	0.68870E+01	0.74785E+01	0.84452E+01
3.00	0.28412E+01	0.47411E+01	0.60201E+01	0.68870E+01	0.74785E+01	0.84452E+01
3.08	0.28412E+01	0.47411E+01	0.60201E+01	0.68870E+01	0.74785E+01	0.84452E+01
3.16	0.28412E+01	0.47411E+01	0.60201E+01	0.68870E+01	0.74785E+01	0.84452E+01

Appendix C

Figures

Figure 1.1. Juvenile stages of the blue crab: (a) Zoeal stage, from hatching through 7-8 molts (30-60 days); and (b) megalopal stage 5 days-2 weeks.

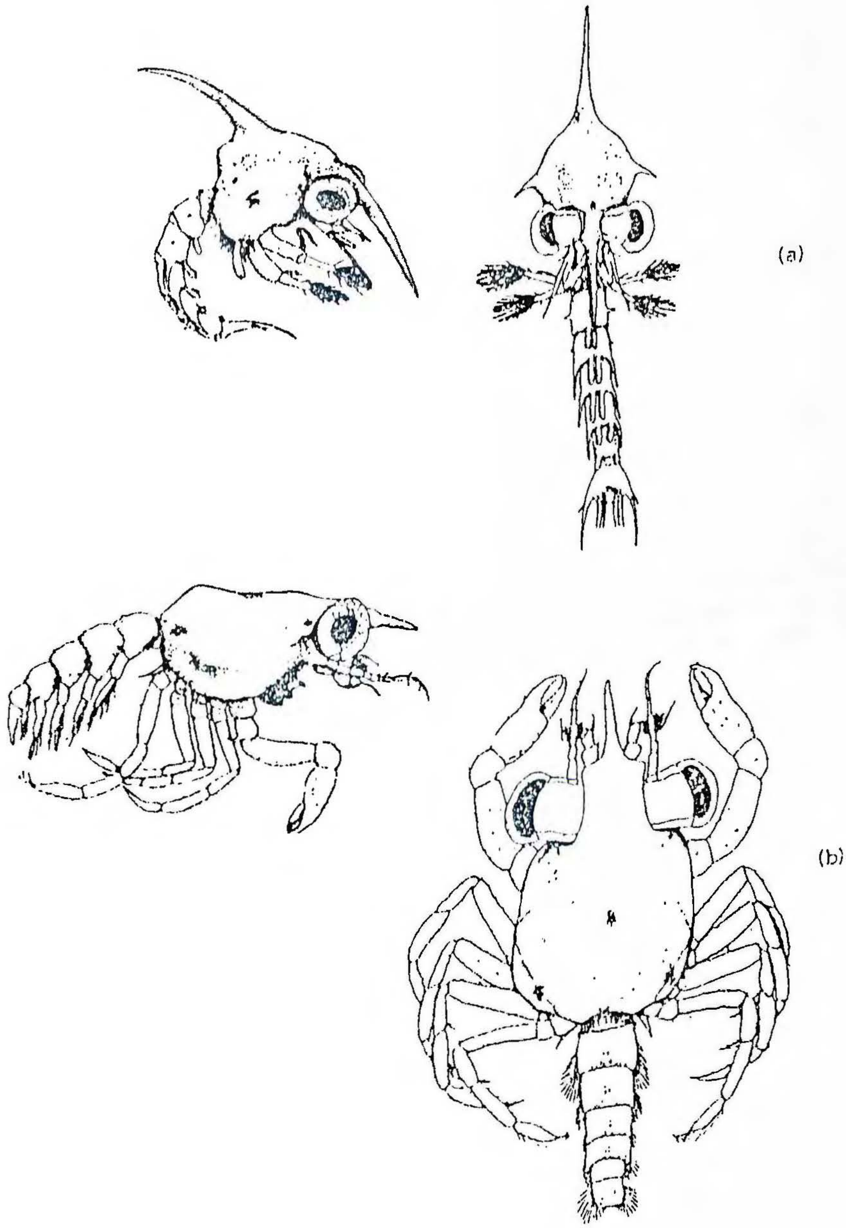
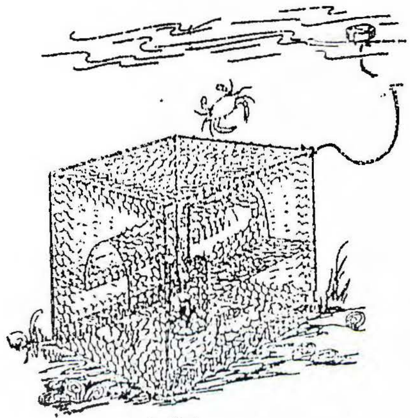
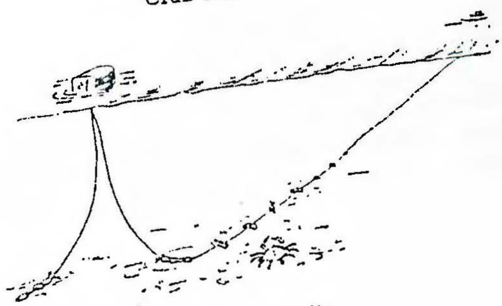

(a)
(b)

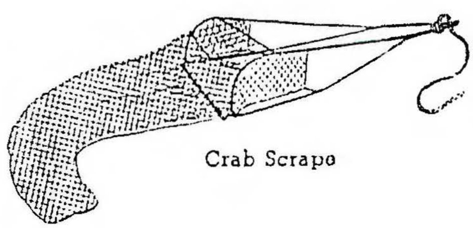
Figure 1.2. Commercial crabbing gear typically used in the Chesapeake Bay. Passive gears include crab pots (a) and trotlines (b); active gears include scrapes (c) and dredges (d).



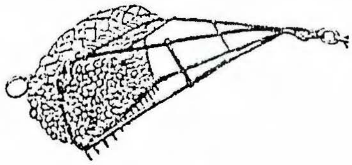
Crab Pot



Trot Lines with Baits



Crab Scrape



Dredge

Figure 1.3. Diagram of the blue crab, illustrating carapace width (distance between the lateral spines); Maryland, Virginia, and the Potomac River have different regulations for minimum carapace width, depending on the condition of the crab (hard, soft, peeler).

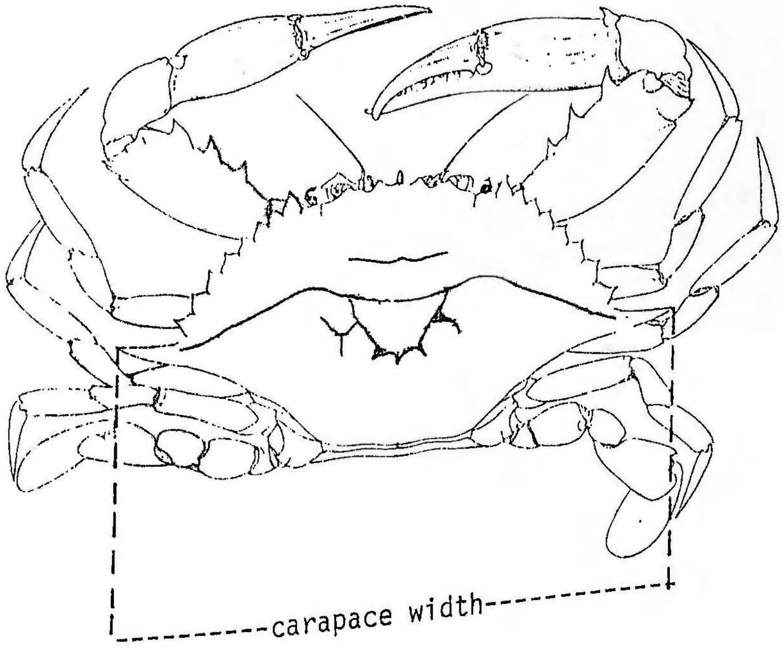

carapace width

Figure 1.4. Reported blue crab commercial catch 1925-1987 in Maryland, Virginia, and the Chesapeake Bay. (Source: NMFS).

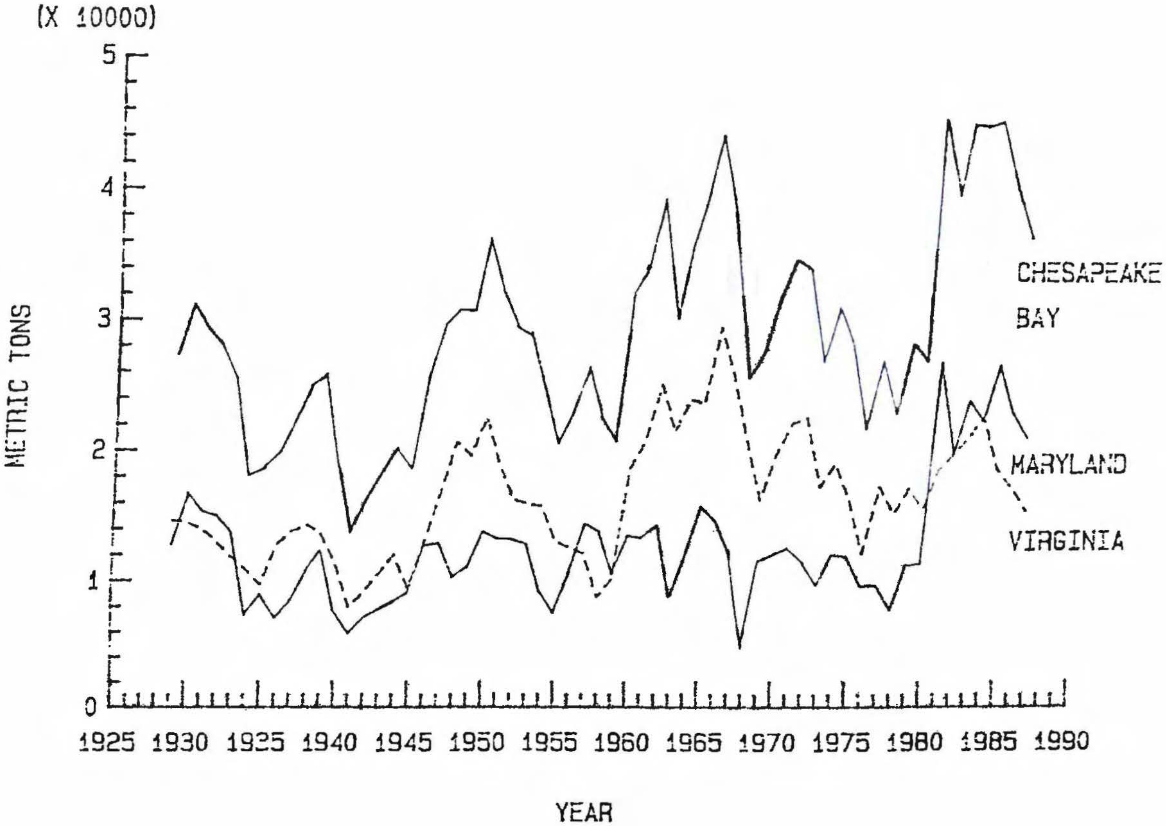

(X 10000)
METRIC TONS
YEAR
CHESAPEAKE BAY
MARYLAND
VIRGINIA
1925 1930 1925 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990

Figure 1.5. Annual reported commercial hard crab catch in the Maryland and Virginia trotline fisheries, 1940-1978. (Source: NMFS).

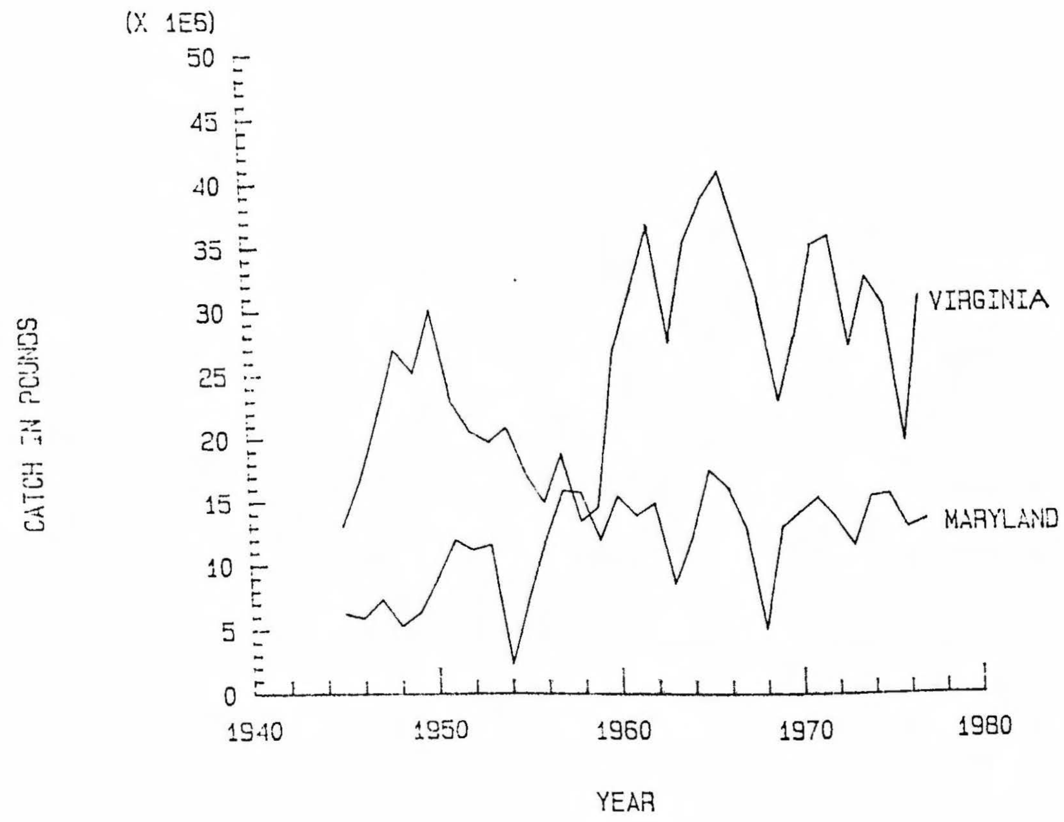

(X 1E6)
50
45
40
35
30
25
20
15
10
5
0
CATCH IN POUNDS
VIRGINIA
MARYLAND
1940
1950
1960
1970
1980
YEAR

Figure 1.6. Annual reported commercial hard crab catch in the Maryland and Virginia pot fisheries, 1944-1978. (Source: NMFS).

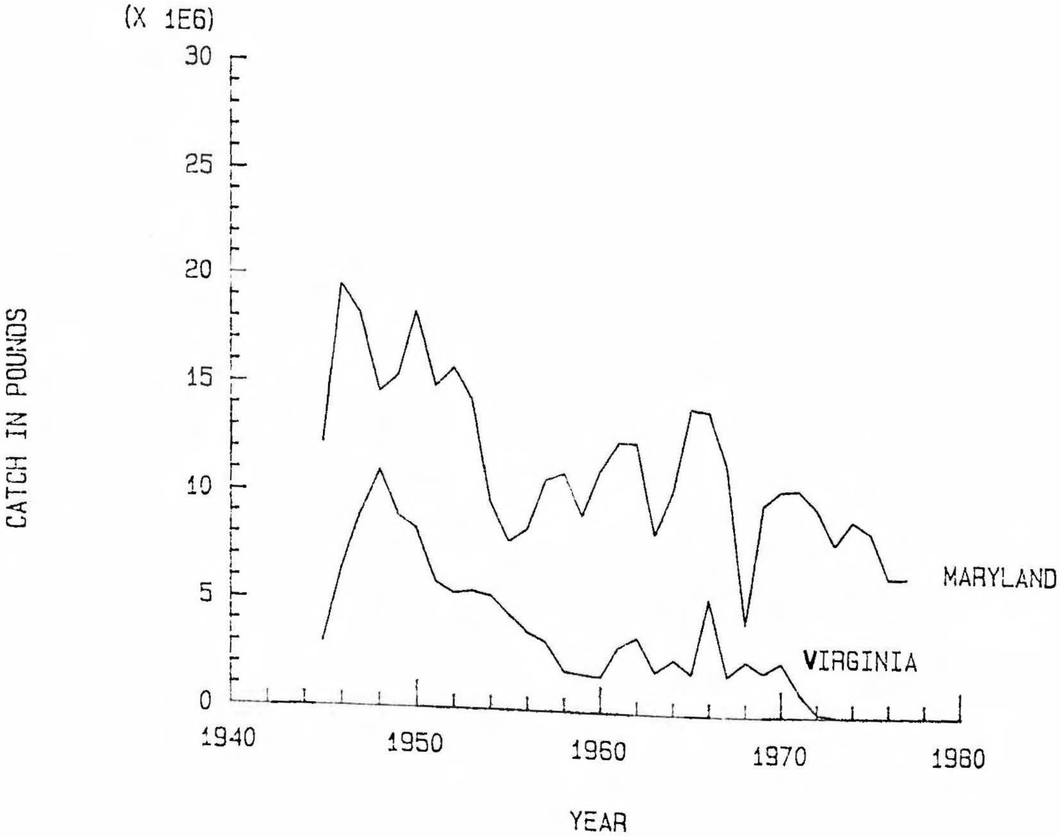

(X 1E6)
30
25
20
15
10
5
0
CATCH IN POUNDS
1940
1950
1960
1970
1980
YEAR
MARYLAND
VIRGINIA

Figure 1.7. Annual reported commercial catch of soft crabs in the Maryland scrape fishery, 1944-1977. (Source: NMFS).

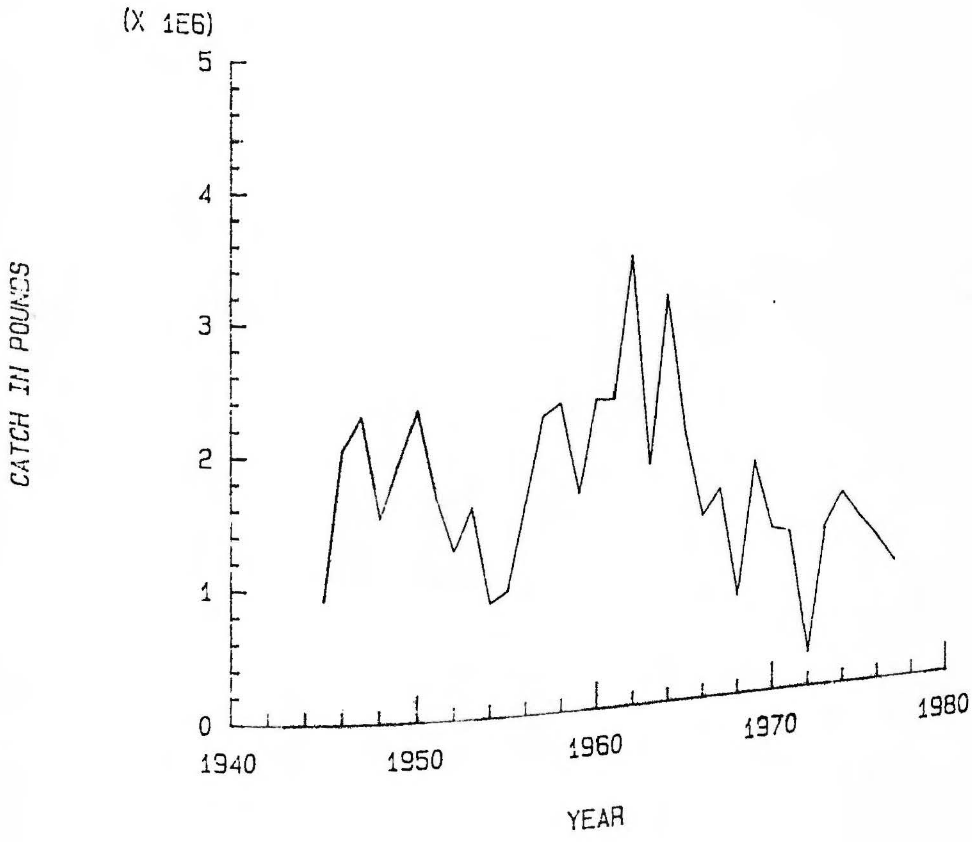

(X 1E6)
CATCH IN POUNDS
0
1
2
3
4
5
1940
1950
1960
1970
1980
YEAR

Figure 1.8. Annual reported commercial catch of soft crabs in the Virginia scrape fishery, 1944-1977. (Source: NMFS).

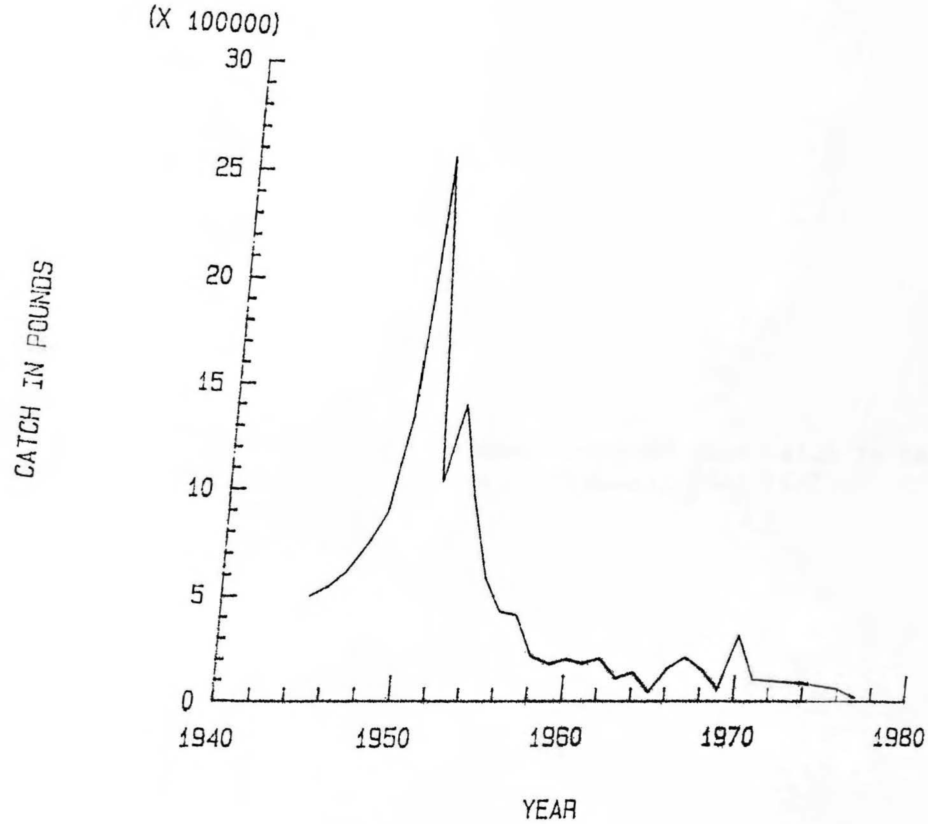

(X 100000)
30
25
20
15
10
5
0
CATCH IN POUNDS
1940
1950
1960
1970
1980
YEAR

Figure 1.9. Annual reported commercial hard crab catch in the Virginia winter dredge fishery, 1945-1977. (Source: NMFS).

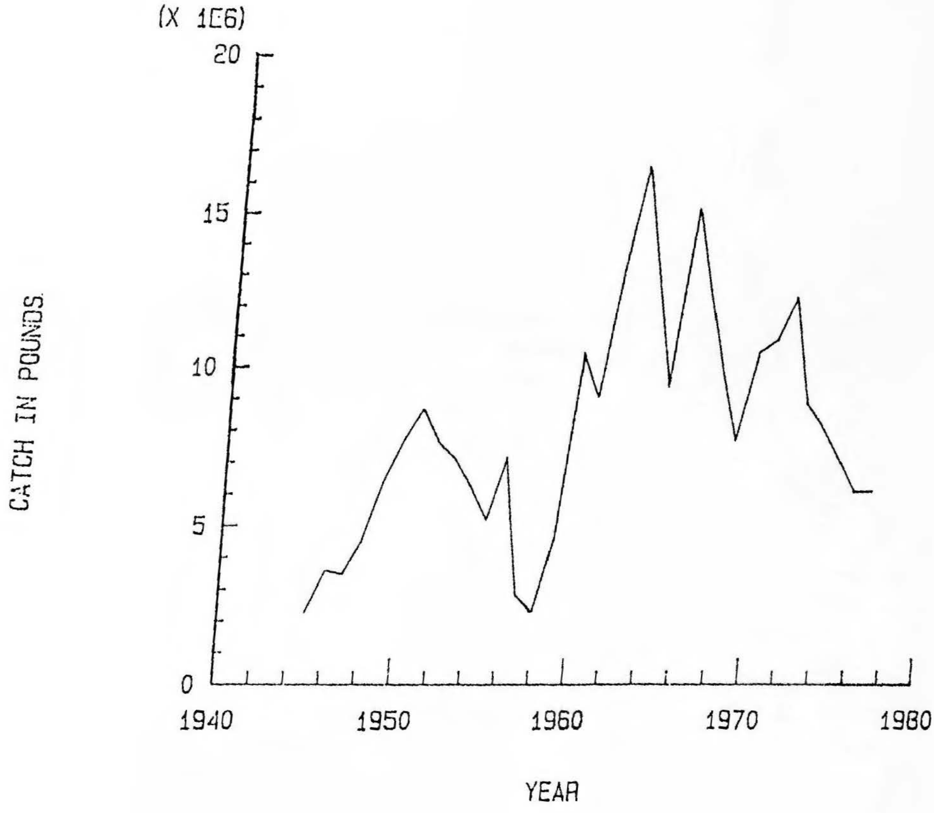
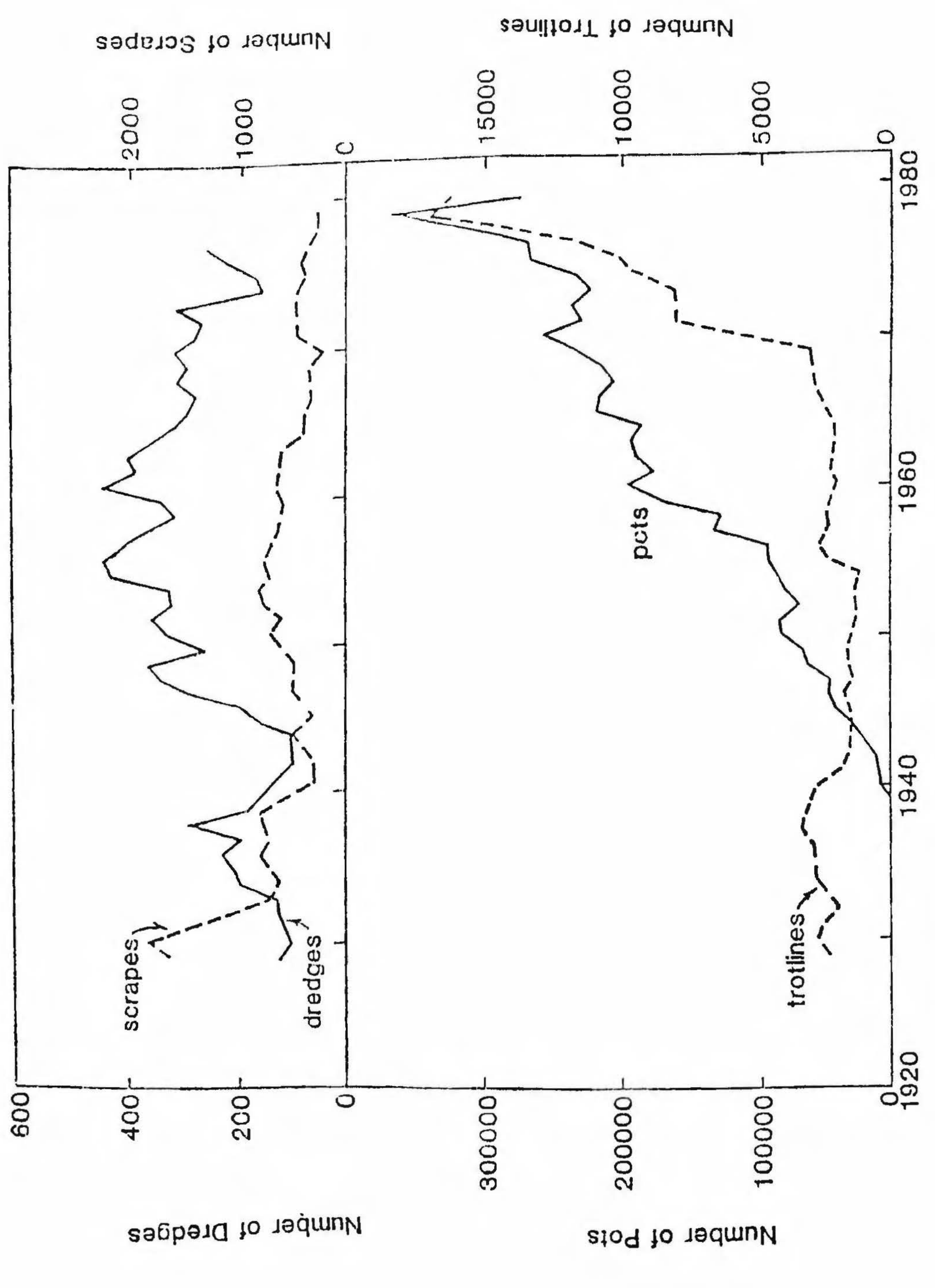
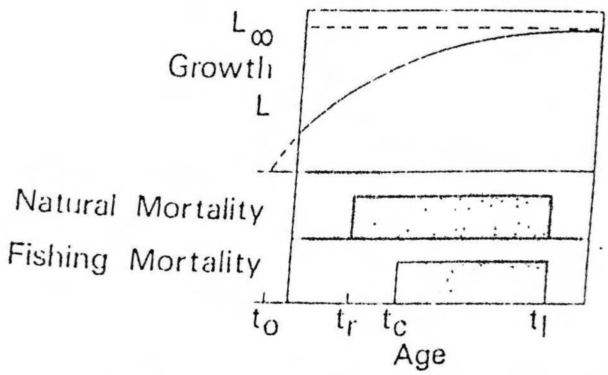

(X 1E6)
20
15
10
5
0
CATCH IN POUNDS
1940
1950
1960
1970
1980
YEAR

Figure 1.10. Total annual reported commercial effort in the Chesapeake Bay scrape, dredge, pot, and trotline fisheries (from Tang, 1983: figure 4).



Number of Dredges
Number of Scrapes
Number of Pots
Number of Trotlines
600
400
200
0
2000
1000
300000
200000
100000
15000
10000
5000
1920
1940
1960
1980
scrapes
dredges
pots
trotlines

Figure 2.1. Classic Beverton and Holt and Ricker yield-per-recruit models. The Ricker model is a simplification of the Beverton-and-Holt model (from Pitcher and Hart, 1982: figure 8.4, and Ricker, 1975)



$$Y = FR\exp(-M(t_c - t_r))\,W_\infty \sum_{n=0}^{n=3}\left\{\left[\frac{U_n}{F+M+nk}\right]\left[\exp(-(nk(t_c - t_0)))\right]\left[1-\exp(-(F+M+nk)(t_l - t_c))\right]\right\}$$

where F = instantaneous rate of fishing mortality
M = instantaneous rate of natural mortality
R = number of recruits
W_∞ = ultimate asymptotic weight from von Bertal. curve
k = von Bertalanffy growth coefficient
t_0 = theoretical age at which fish have zero length
t_r = age at recruitment to fishable stock
t_c = actual age at first capture with given gear
t_l = maximum age of fish in stock
U_n = integration constants necessitated by use of the von Bertalanffy growth model, $U_0 = 1$; $U = -3$; $U_2 = 3$; $U_3 = 1$.

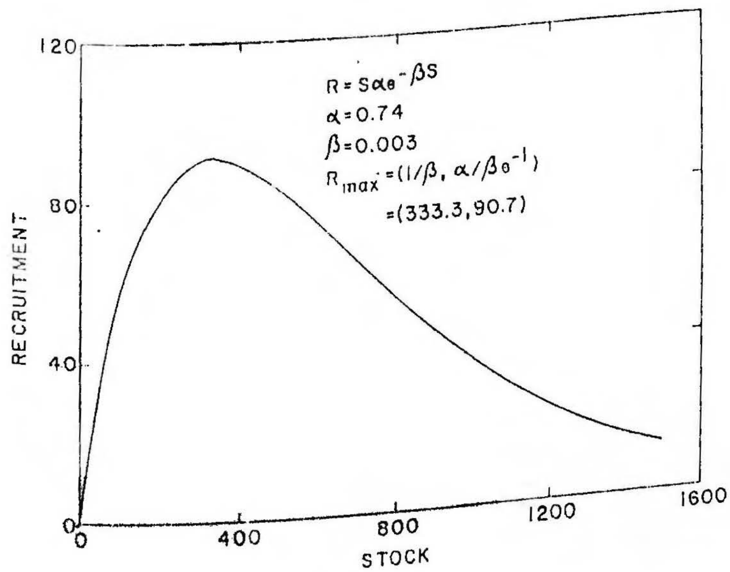
$$Y_E = \sum_{t=t_R}^{t=t_\lambda} F_t\overline{B}_t$$

$$Y_E = \sum_{t=t_R}^{t=t_\lambda}\left(\frac{F_tB_t[1 + e^{G_t-Z_t}]}{2}\right)$$

$$\overline{B}_t = \frac{B_t(e^{G_t-Z} - 1)}{G_t - Z_t}$$

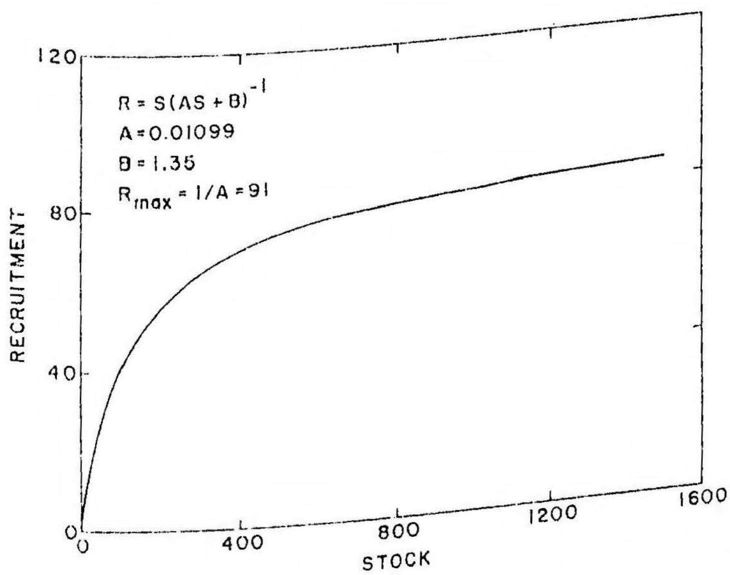
where t = successive intervals in the life of the fish
t_R = the first interval under consideration
t_λ = the last period under consideration
B = biomass of of the stock
G = instantaneous rate of growth
Z = instantaneous rate of (total) mortality
F = instantaneous rate of fishing mortality

Figure 2.2. Classic Ricker and Beverton and Holt recruitment-stock curves. Curve (a) is a Ricker curve; curve (b) is a Beverton and Holt curve. (From Rothschild, 1986: figure 5.1).



$R = S\alpha e^{-\beta S}$
$\alpha = 0.74$
$\beta = 0.003$
$R_{max} = (1/\beta, \alpha/\beta e^{-1})$
$= (333.3, 90.7)$
RECRUITMENT
STOCK
0
40
80
120
0
400
800
1200
1600

(a)



$R = S(AS + B)^{-1}$
$A = 0.01099$
$B = 1.35$
$R_{max} = 1/A = 91$
RECRUITMENT
STOCK
0
40
80
120
0
400
800
1200
1600

(b)

Figure 2.3. Schaefer, Pella and Tomlinson, and Fox production models, which are derived from logistic surplus production model. (From Tang, 1983)

Schaefer Model

$$Y_e = B_\infty q f - \frac{B_\infty q^2}{K} f^2$$

$$MSY = \frac{(B_\infty q)^2}{4} \cdot \frac{K}{B_\infty q^2}$$

$$f_{opt} = \frac{B_\infty q}{2} \cdot \frac{K}{B_\infty q^2}$$

Pella and Tomlinson Model

$$Y_e = f\left(B_\infty^{\,m-1} q^{m-1} - \frac{g^m B_\infty^{\,m-1}}{K} f\right)^{\frac{1}{m-1}} \quad (6)$$

$$MSY = \left(q^{m-1} B_\infty^{\,m-1}\right)\left(\frac{K}{q^m B_\infty^{\,m-1}}\right)\left(\frac{1}{m} - 1\right)\left(\frac{q^{m-1} B_\infty^{\,m-1}}{m}\right)^{\frac{1}{m-1}}$$

$$f_{opt} = \left(q^{m-1} B_\infty^{\,m-1}\right)\left(-\frac{K}{q^m B_\infty^{\,m-1}}\right)\left(\frac{1}{m} - 1\right)$$

Fox Model

$$Y_e = f B_\infty q e^{-\frac{q}{k} f}$$

$$MSY = B_\infty q e^{-1}\left(\frac{k}{q}\right)$$

$$f_{opt} = \frac{K}{q}$$

where Y_e = equilibrium yield,

MSY = maximum equilibrium yield, and

f_{opt} = effort at MSY

Simplyfing these models gives:

$$U = a - bf$$

$$U_{opt} = \frac{a}{2}$$

$$U^{m-1} = a' - b'f$$

$$U_{opt} = \left(\frac{a'}{m}\right)^{\frac{1}{m-1}}$$

$$\log_e U = a'' - b''f$$

$$U_{opt} = e^{a''-1}$$

Figure 2.4. Map of the Maryland portion of the Chesapeake Bay, showing the eight general data collection areas for the 1987 commercial blue crab fishery survey (from Rothschild et. al., 1988: figure 2).

Chesapeake Bay

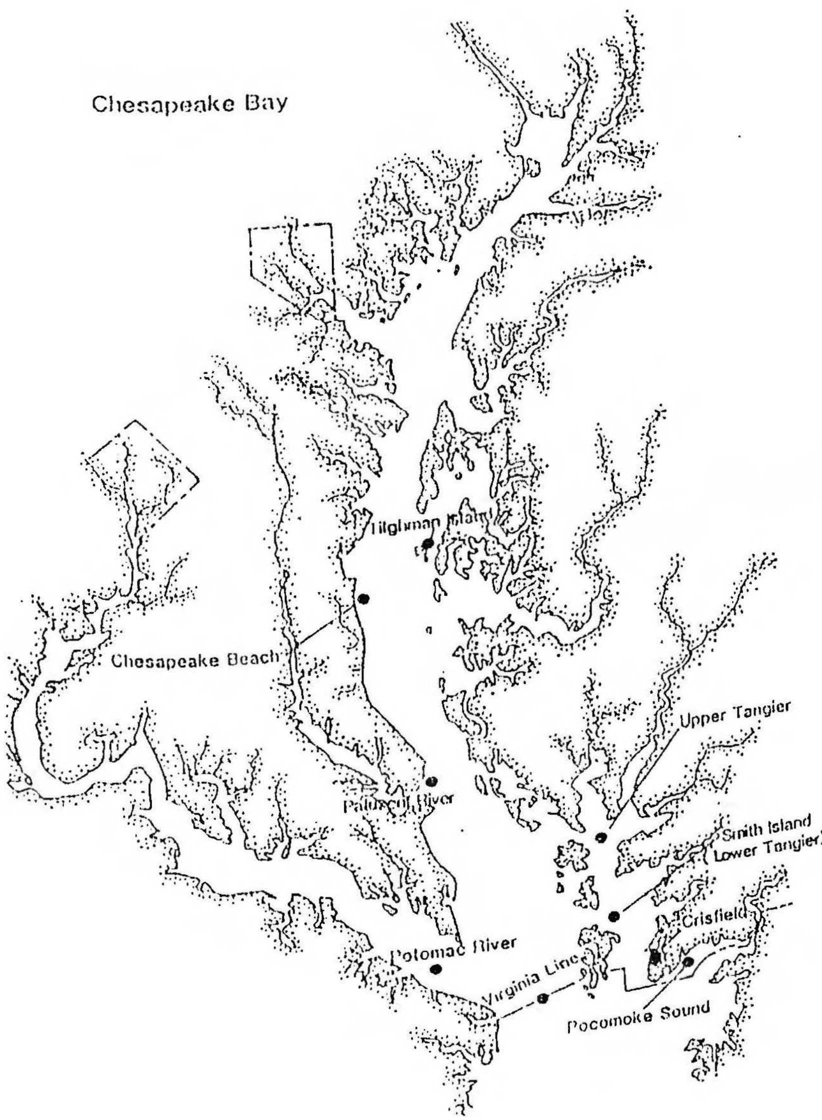


Figure 2.5. Sample data sheet from a commercial pot fishery sampling day in the 1987 Maryland commercial fishery survey.

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Center for Environmental and Estuarine Studies
Chesapeake Biological Laboratory

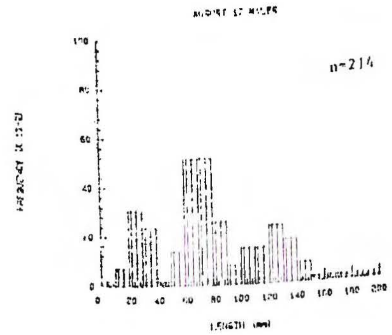
POT #	L	S	C	POT #	L	S	C	POT #	# CRABS	BAIT TYPE	SOAK TIME (HRS)	POT DIM	DEPTH
3	117	1	1	21	142	2	8	1	13	[illegible]	24	E	6-8 FT
	160	1	1		136	1	1	2	9				
	130	1	1		112	1	1	3	11				
	123	1	1		150	2	8	4	5				
	131	1	1		137	1	1	5	9				
	134	1	1	24	118	1	1	6	1				
	126	1	1		132	1	1	7	6				
	127	1	1		110	1	1	8	10				
	117	1	1		127	1	1	9	4				
	122	1	1		138	1	1	10	7				
	124	1	1		107	1	1	11	5				
7	90	2	7		120	1	1	12	2				
	129	1	1		134	1	1	13	6				
	121	1	1		129	1	1	14	10				
	127	1	1	26	134	1	1	15	8				
	121	1	1		131	1	1	16	10				
	118	2	7		126	1	1	17	7				
10	121	1	1		138	2	8	18	8				
	132	1	1		141	1	1	19	4				
	95	2	7		122	1	1	20	0				
	120	1	1		126	1	1	21	5				
	120	1	1		140	2	8	22	5				
	124	1	1	27	120	1	1	23	7				
	125	1	1		123	1	1	24	9				
12	137	1	1		115	1	1	25	9				
	152	2	8		107	1	1	26	8				
	122	1	1		120	1	1	27	10				
	120	1	1		105	1	1						
	123	1	1		108	1	1						
	126	1	1		92	1	1						
11	130	1	1		97	1	1						
	122	1	1		136	1	1						
	130	1	1										
	120	1	1										
	124	1	1										
	117	1	1										

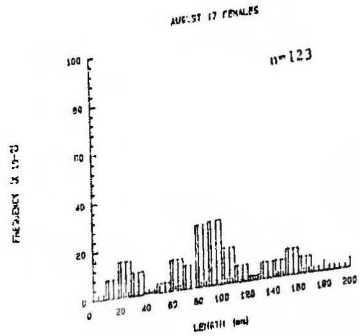
L = length (mm)
S = sex

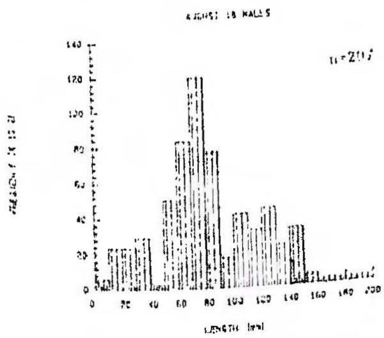
C = condition
1 - hard
2 -
3 - peeler
4 - soft
5 - sponge
6 - dead
7 - immature
8 - mature

Pot Dimensions:
A - 20" coated 1 1/2" mesh
B - 20" uncoated 1 1/2" mesh
C - 20" coated 1" mesh
D - 20" uncoated 1" mesh
E - 24" coated 1 1/2" mesh
F - 24" uncoated 1 1/2" mesh
G - 24" coated 1" mesh
H - 24" uncoated 1" mesh
I -
J -

Figure 2.6. Examples of effort-adjusted length frequency histograms by sampling date, by sex (males, left panel; females, right panel) with sample size (unit of effort is catch-per-scrape-minute). (From Rothschild et. al., 1988: figure 20).


n=214
LENGTH (mm)


AUGUST 17 FEMALES
n=123
LENGTH (mm)


LENGTH (mm)

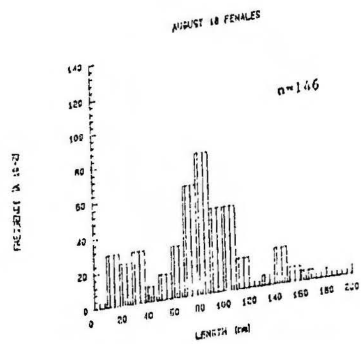
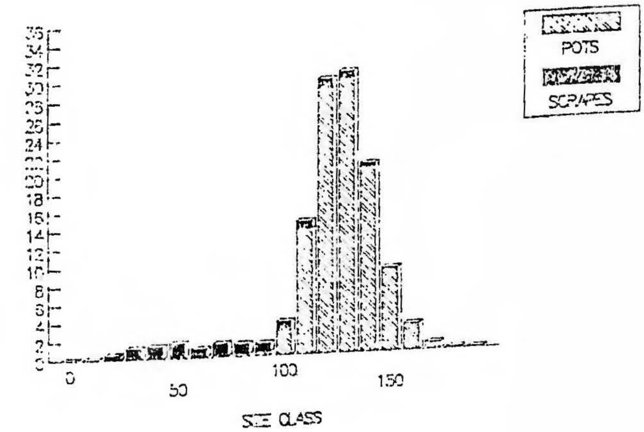
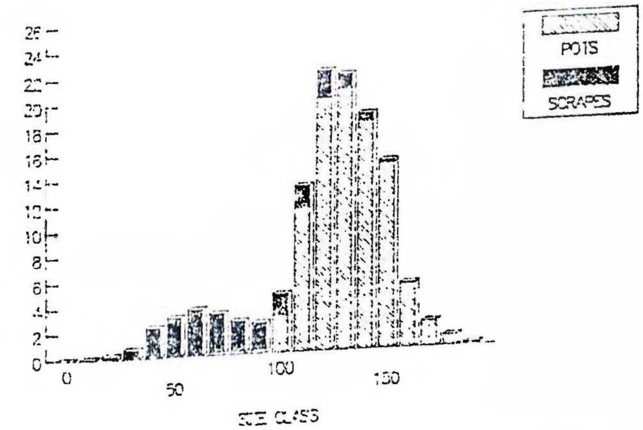

AUGUST 18 FEMALES
n=146
LENGTH (mm)

Figure 2.7. Monthly total of daily average catch-per-unit-effort of male blue crabs in the commercial pot and scrape fisheries sampled in the months of: (a)June, 1987, (b)July, 1987, (c)August, 1987.

(a)


POTS
SCRAPES
0
50
100
150

(b)


POTS
SCRAPES
0
50
100
150

(c)

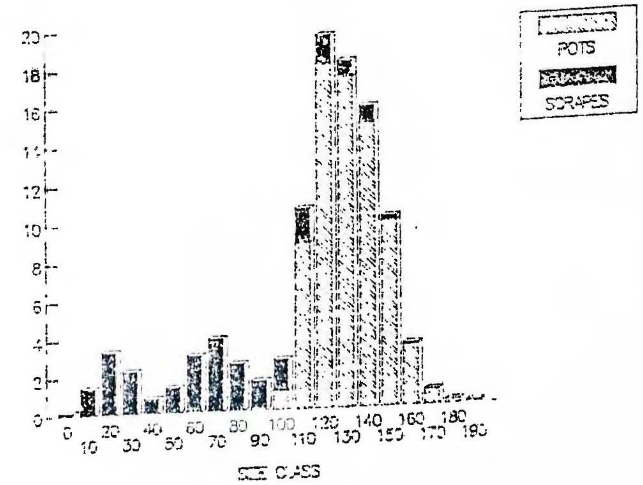

POTS
SCRAPES

Figure 2.8. Monthly total of daily average catch-per-unit-effort of female blue crabs in the commercial pot and scrape fisheries sampled in the months of: (a)June, 1987, (b)July, 1987, (c)August, 1987.

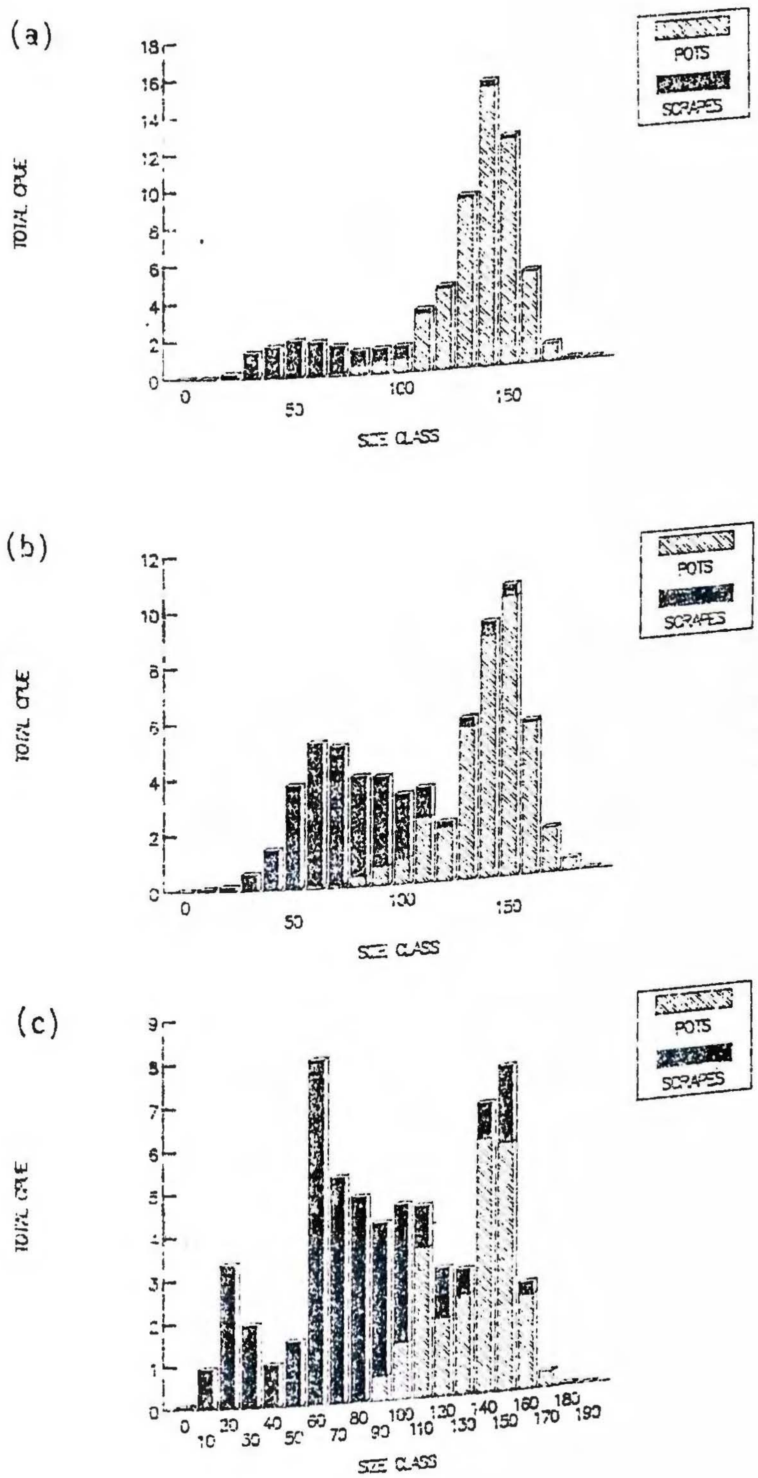

(a)
POTS
SCRAPES
TOTAL CPUE
SIZE CLASS
(b)
POTS
SCRAPES
TOTAL CPUE
SIZE CLASS
(c)
POTS
SCRAPES
TOTAL CPUE
SIZE CLASS

Figure 2.9. Plot of empirical length-frequency distribution modes, obtained through Petersen's method of length-frequency distribution analysis. The length-frequency distributions analyzed were the monthly total of daily average catch-per-unit-effort of female blue crabs in the commercial pot and scrape fisheries sampled in June, July, and August, 1987.

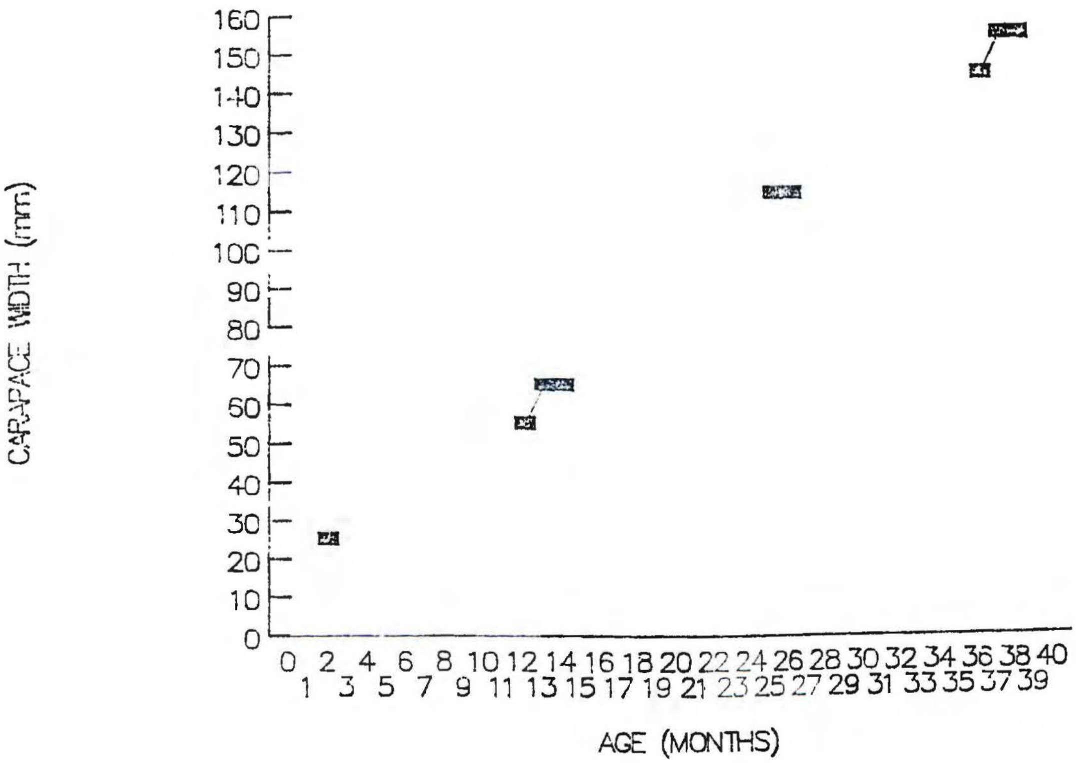
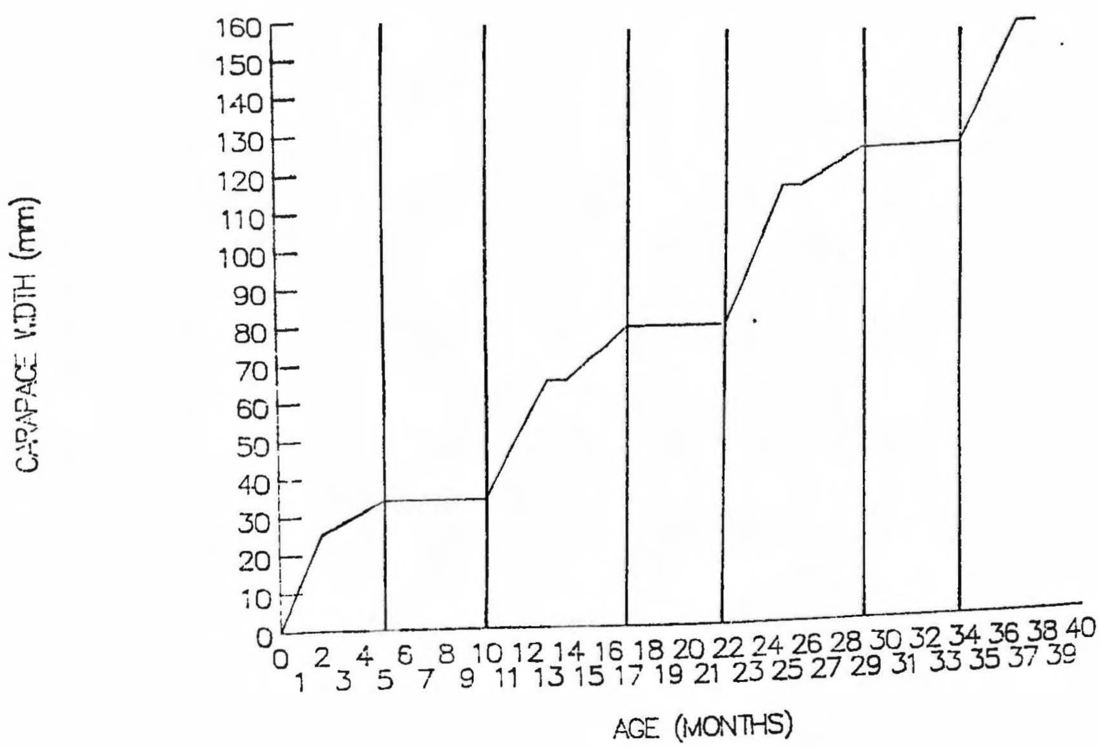

CARAPACE WIDTH (mm)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39
AGE (MONTHS)

Figure 2.10. Curve connecting empirical length-frequency distribution modes, obtained through Petersen's method of length-frequency distribution analysis. The length-frequency distributions analyzed were the monthly total of daily average catch-per-unit-effort of female blue crabs in the commercial pot and scrape fisheries sampled in June, July, and August, 1987. The plateaus shown correspond to winter months (November-April) in which blue crabs semi-hibernate, and growth does not occur.


CARAPACE WIDTH (mm)
AGE (MONTHS)

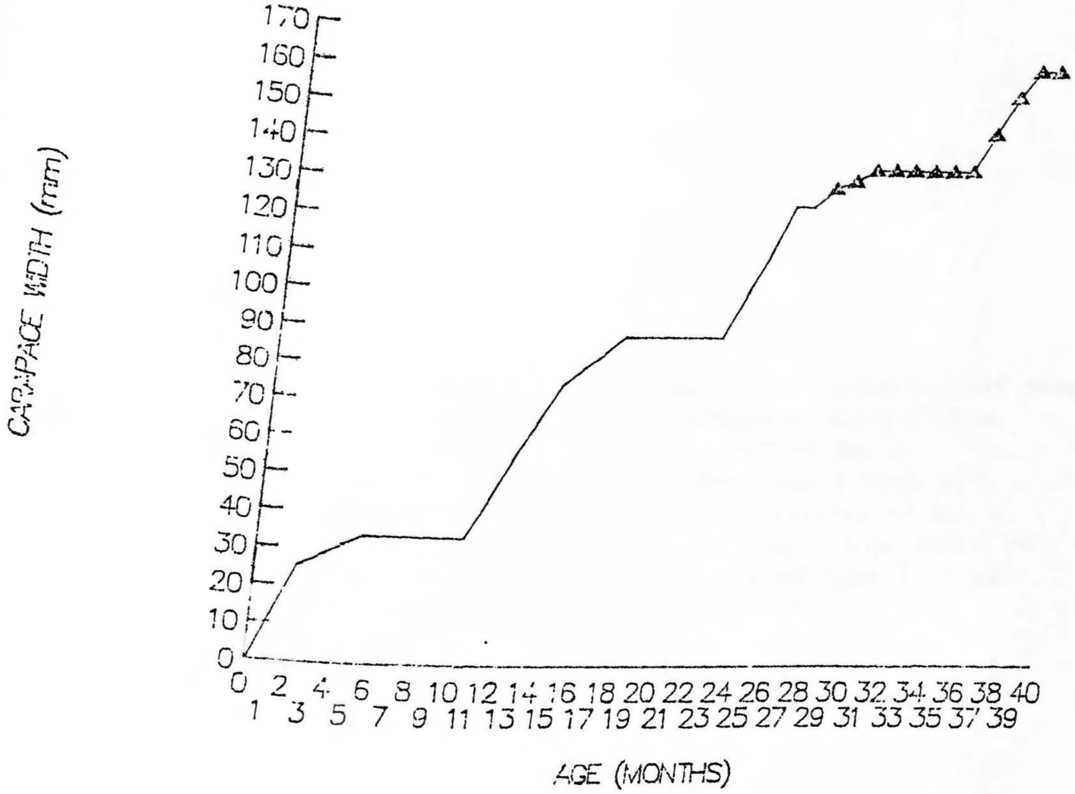
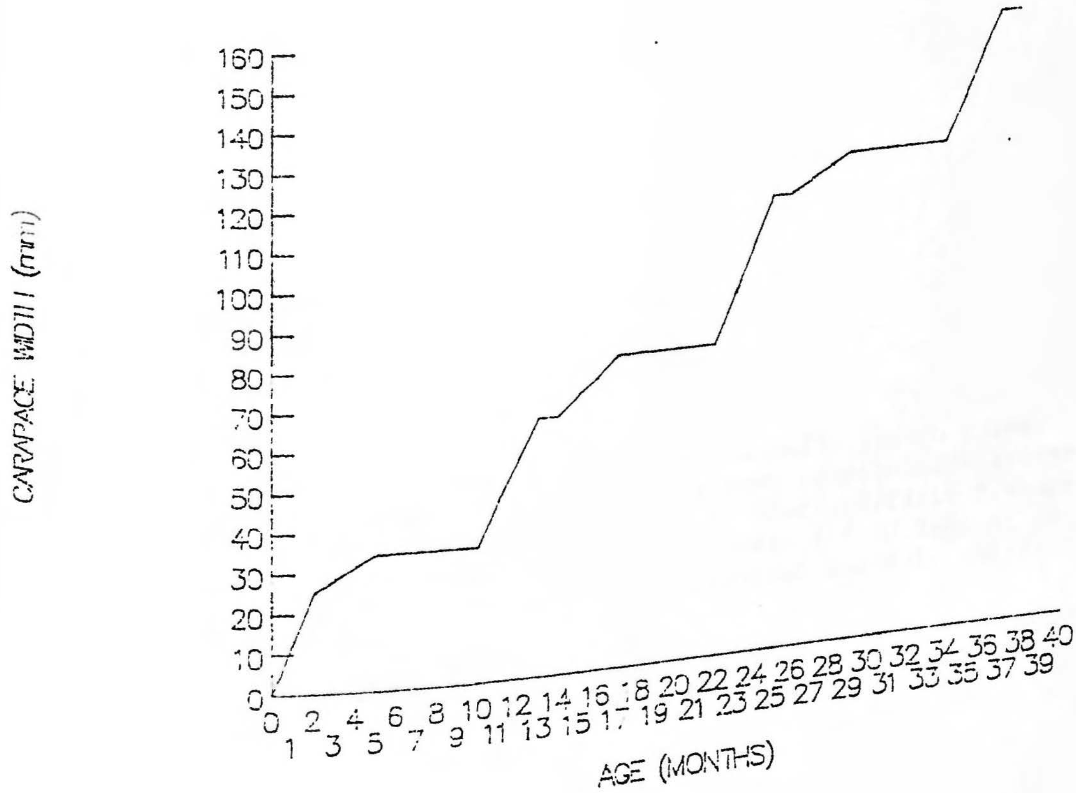

CARAPACE WIDTH (mm)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
AGE (MONTHS)

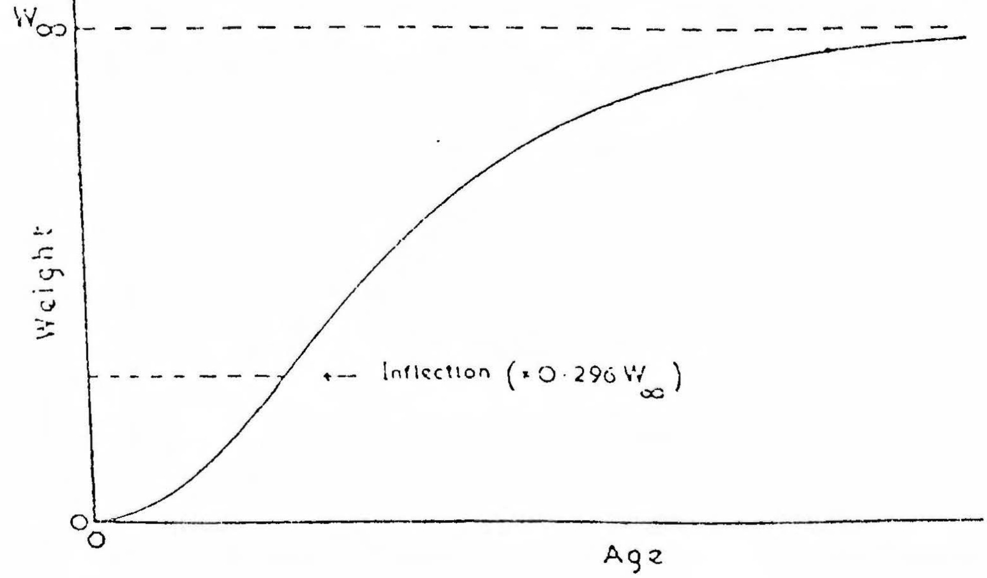
Figure 2.11. Empirical growth curve for male blue crabs derived from Petersen's method of length-frequency distribution analysis. The plateaus where no growth occurs correspond to winter periods (Nov.-Apr.) when blue crabs undergo semi-hibernation. (Note: portion of curve overlaid with triangles is an approximation, based on the assumption that growth of males of ages 2.16 years to 3.16 years parallels that of females).

Figure 2.12. Empirical growth curve for female blue crabs derived from Petersen's method of length-frequency distribution analysis. The plateaus where no growth occurs correspond to winter periods (Nov.-Apr.) when blue crabs undergo semi-hibernation.



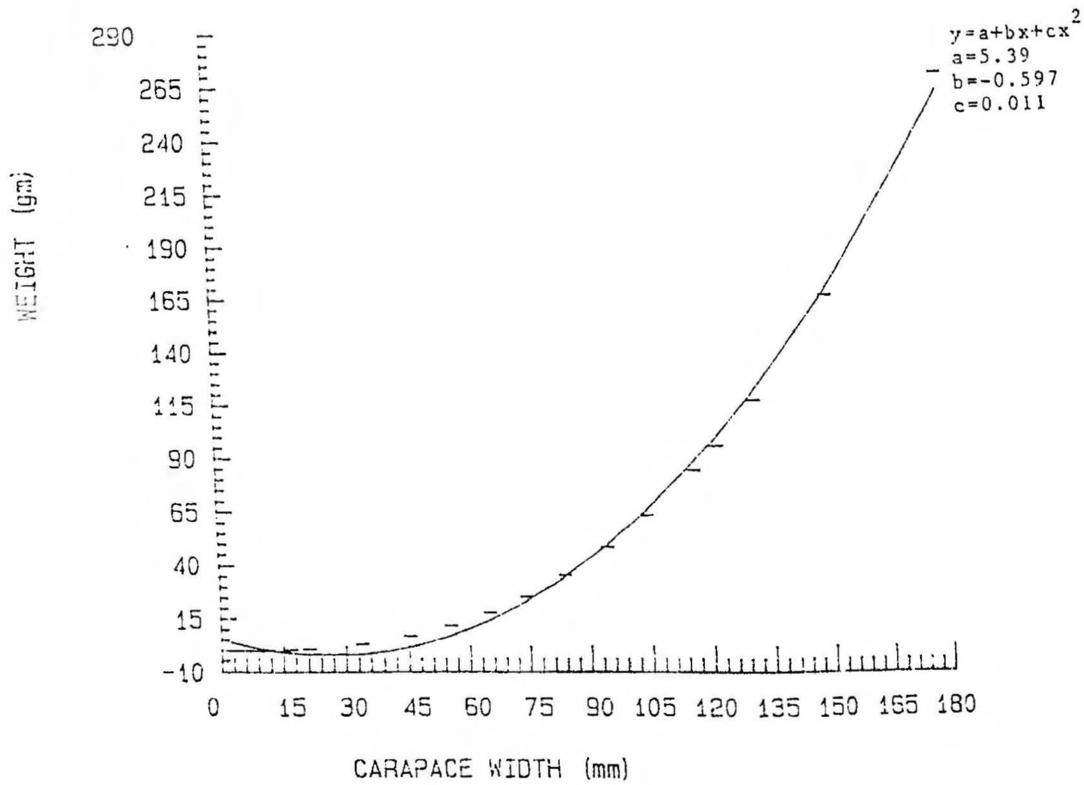
CARAPACE WIDTH (mm)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
AGE (MONTHS)

Figure 2.13. The general form of the von Bertalanffy growth curve given by the von Bertalanffy growth equation for growth in length or weight, showing the characteristic S-shape with an inflexion slightly less than 1/3 (0.296) of the asymptotic length or weight (Beverton and Holt, 1957: figure 3.1).



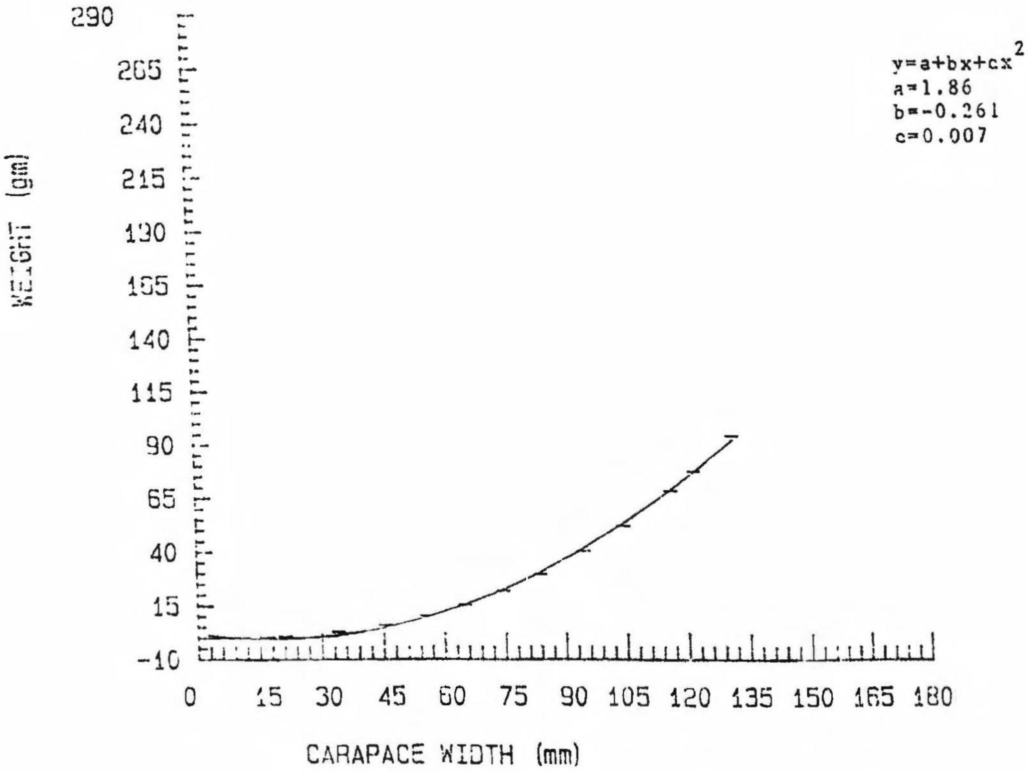
W_∞
Weight
Inflection ($\approx 0.296\,W_\infty$)
0
0
Age

Figure 2.14. Carapace width-weight curve fit to historical laboratory data for male Chesapeake Bay blue crabs. The equation of the curve, and the parameters are shown.



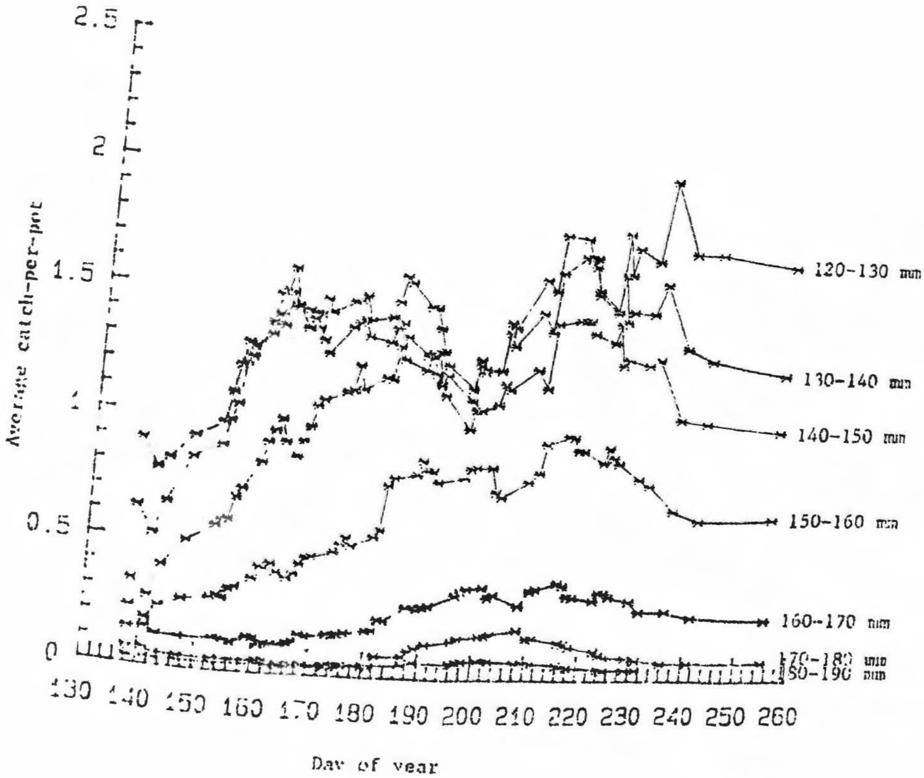
y=a+bx+cx2
a=5.39
b=-0.597
c=0.011
WEIGHT (gm)
290
265
240
215
190
165
140
115
90
65
40
15
-10
0 15 30 45 60 75 90 105 120 135 150 165 180
CARAPACE WIDTH (mm)

Figure 2.15. Carapace width-weight curve fit to historical laboratory data for female Chesapeake Bay blue crabs. The equation of the curve, and the parameters are shown.



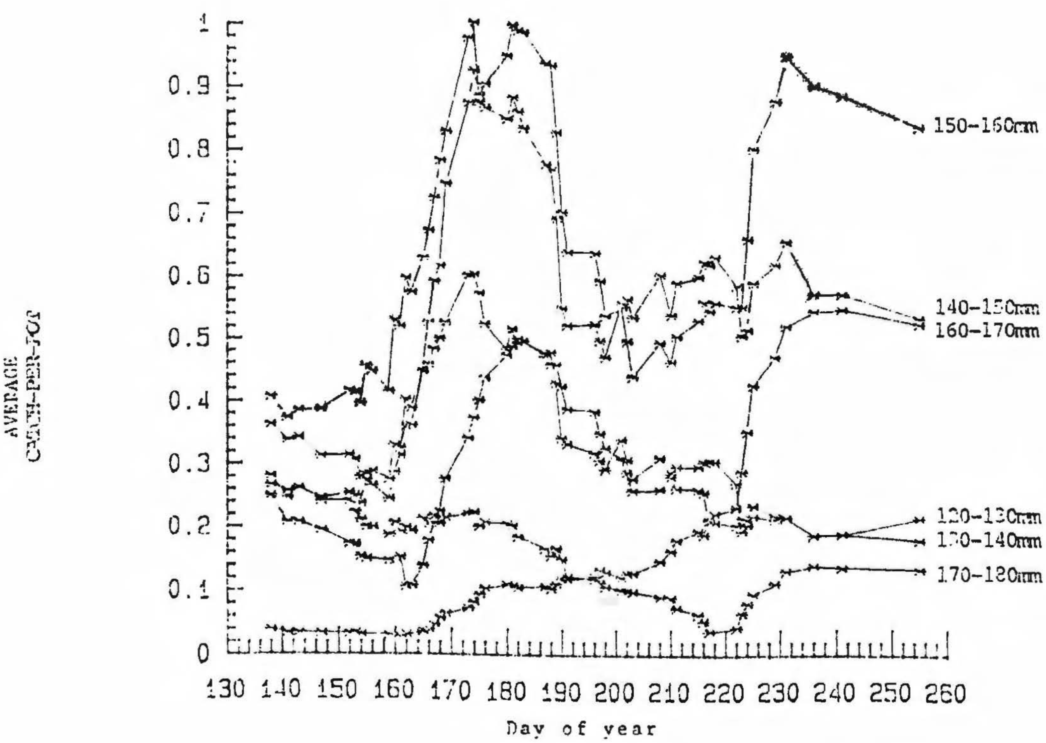
290
265
240
215
190
165
140
115
90
65
40
15
-10
WEIGHT (gm)
0 15 30 45 60 75 90 105 120 135 150 165 180
CARAPACE WIDTH (mm)
y=a+bx+cx^2
a=1.86
b=-0.261
c=0.007

Figure 2.16. Average catch-per-pot by size class over time for male blue crabs sampled throughout the Chesapeake Bay and recruited to the Maryland pot fishery.



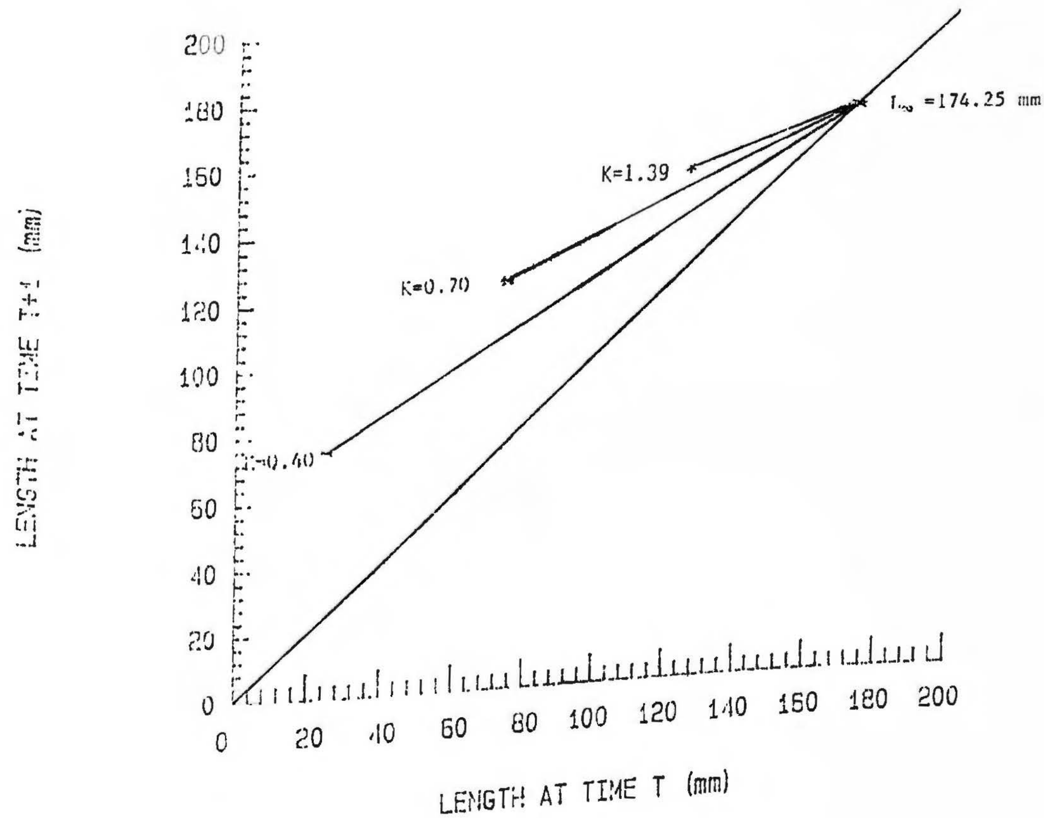
Average catch-per-pot
2.5
2
1.5
1
0.5
0
120-130 mm
130-140 mm
140-150 mm
150-160 mm
160-170 mm
170-180 mm
180-190 mm
130 140 150 160 170 180 190 200 210 220 230 240 250 260
Day of year

Figure 2.17. Average catch-per-pot by size class over time for female blue crabs sampled throughout the Chesapeake Bay and recruited to the Maryland pot fishery.



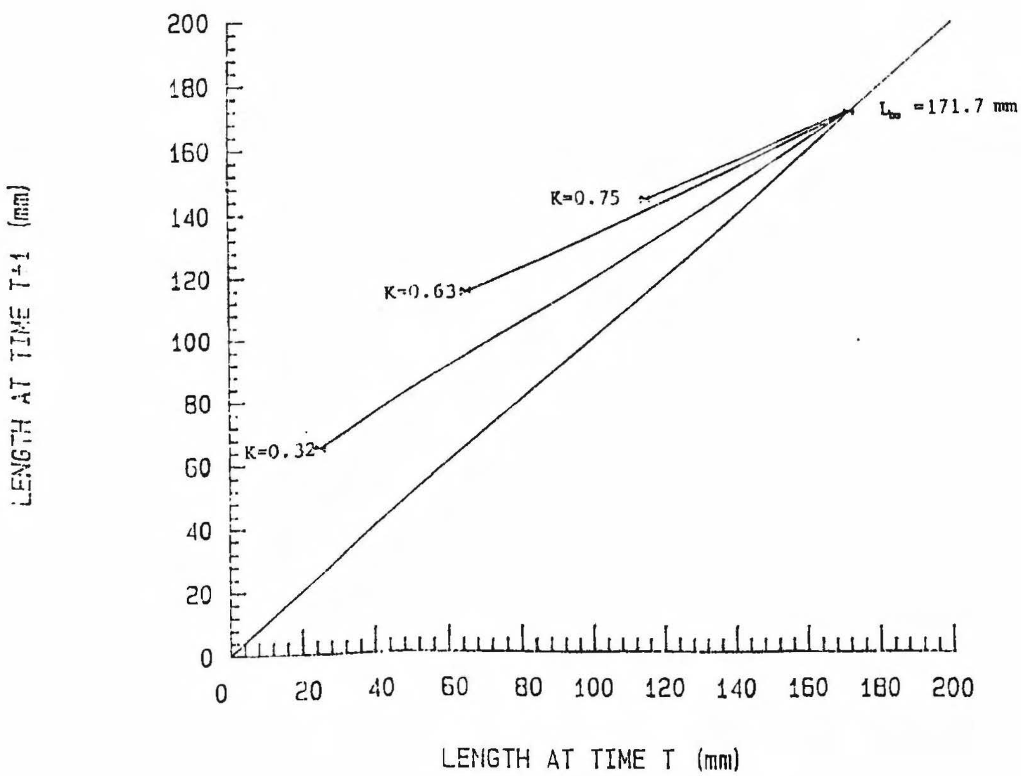
AVERAGE
CATCH-PER-POT
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
130 140 150 160 170 180 190 200 210 220 230 240 250 260
Day of year
150-160mm
140-150mm
160-170mm
120-130mm
130-140mm
170-180mm

Figure 2.18. Walford plot, with von Bertalanffy growth coefficients, and 45^{o} line for male blue crabs, ages 2,14 months ($K=0.40$), 14,26 months ($K=0.70$), and 26,38 months ($K=1.39$).



L∞ =174.25 mm
K=1.39
K=0.70
K=0.40
LENGTH AT TIME T+1 (mm)
LENGTH AT TIME T (mm)
0
20
40
60
80
100
120
140
160
180
200

Figure 2.19. Walford plot, with von Bertalanffy growth coefficients, and 45° line for female blue crabs, ages 2,14 months (K=0.32), 14,26 months (K=0.63), and 26,38 months (K=0.75).



LENGTH AT TIME T+1 (mm)
LENGTH AT TIME T (mm)
K=0.75
K=0.63
K=0.32
L_∞ =171.7 mm
0
20
40
60
80
100
120
140
160
180
200

Figure 2.20. Beverton-and-Holt method for approximation of instantaneous total mortality rate (Z) from age composition of catch.

$$Z = \frac{1}{\text{average age after recruitment}}$$

Age	Number of individuals (N)	Coded age	N*coded age
1	10,000.0		
2	5,000.0	1	5,000.0
3	2,500.0	2	5,000.0
4	1,250.0	3	3,750.0
5	625.0	4	2,500.0
6	312.5	5	1,562.5
	9,687.5		17,812.5

$$\text{Average age after recruitment} = \frac{\text{N*coded age}}{\text{N at coded age}}$$

$$= \frac{5000+5000+3750+2500+1562.5}{5000+2500+1250+625+312.5} = \frac{17{,}812.5}{9{,}687.5}$$

$$= 1.84$$

Therefore,

$$Z = \frac{1}{1.84} = 0.54$$

and,

$$S = e^{-Z} = 0.58$$

Figure 2.21. Yield-per-recruit as a function of fishing mortality (F) for various lengths at first capture (minimum size) for male blue crabs with varying natural mortality rates: (a)M=0.30, (b)M=0.50, (c)M=0.70.

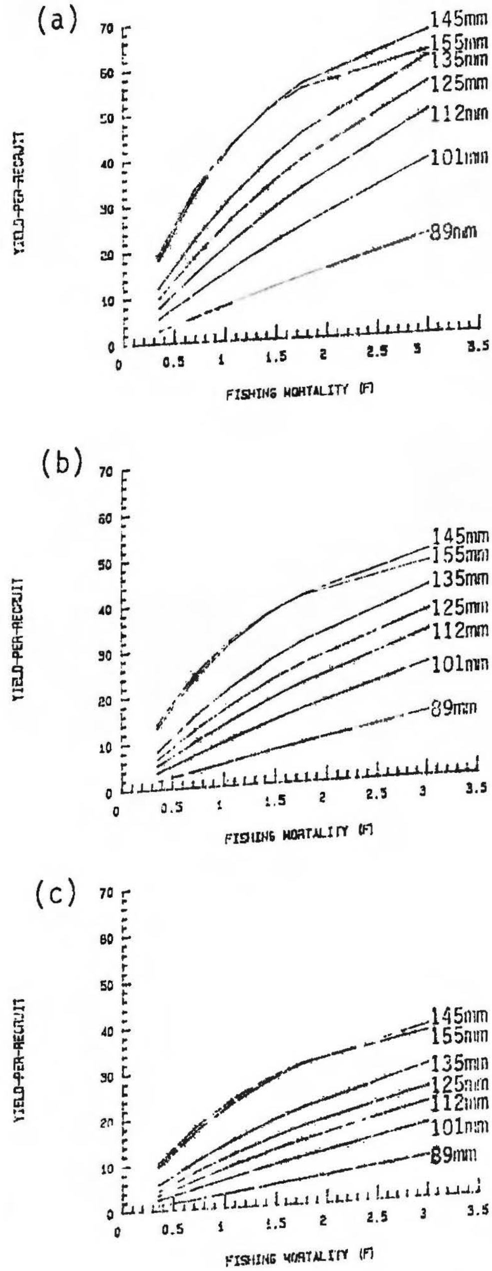
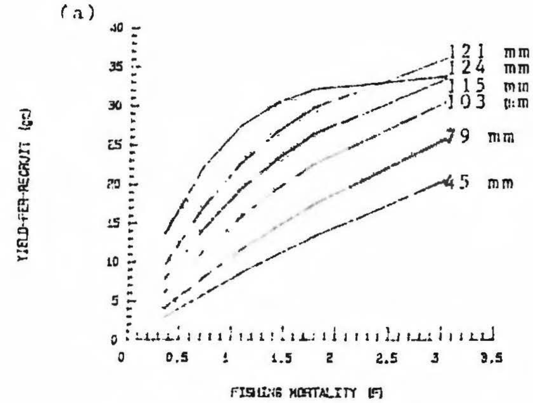
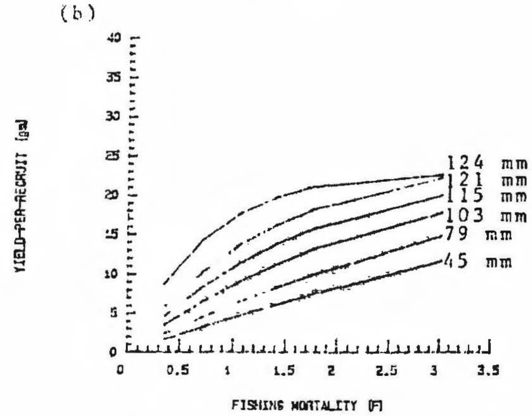

(a)
145mm
155mm
135mm
125mm
112mm
101mm
89mm
YIELD-PER-RECRUIT
FISHING MORTALITY (F)
(b)
145mm
155mm
135mm
125mm
112mm
101mm
89mm
YIELD-PER-RECRUIT
FISHING MORTALITY (F)
(c)
145mm
155mm
135mm
125mm
112mm
101mm
89mm
YIELD-PER-RECRUIT
FISHING MORTALITY (F)

Figure 2.22. Yield-per-recruit as a function of fishing mortality (F)for various lengths at first capture (minimum size) for female blue crabs with varying natural mortality rates: (a)M=0.3, (b)M=0.50, (c)M=0.70.

(a)


YIELD-PER-RECRUIT (gm)
FISHING MORTALITY (F)
121 mm
124 mm
115 mm
103 mm
79 mm
45 mm

(b)


YIELD-PER-RECRUIT (gm)
FISHING MORTALITY (F)
124 mm
121 mm
115 mm
103 mm
79 mm
45 mm

(c)

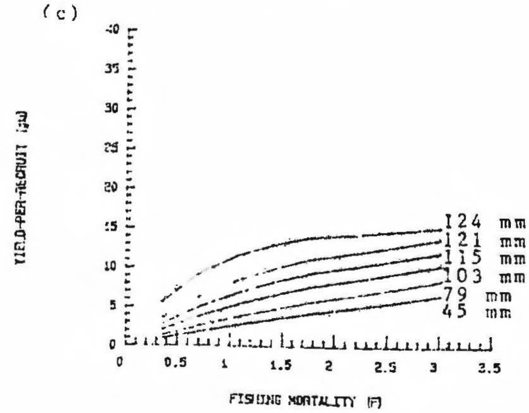

YIELD-PER-RECRUIT (gm)
FISHING MORTALITY (F)
124 mm
121 mm
115 mm
103 mm
79 mm
45 mm

Figure 2.23. Yield-per-recruit as a function of age at first capture with constant fishing rates for male blue crabs with varying natural mortality rates: (a)M=0.30, (b)M=0.40, (c)M=0.50. (Numbers in parentheses on x-axis are size-at-age in mm).

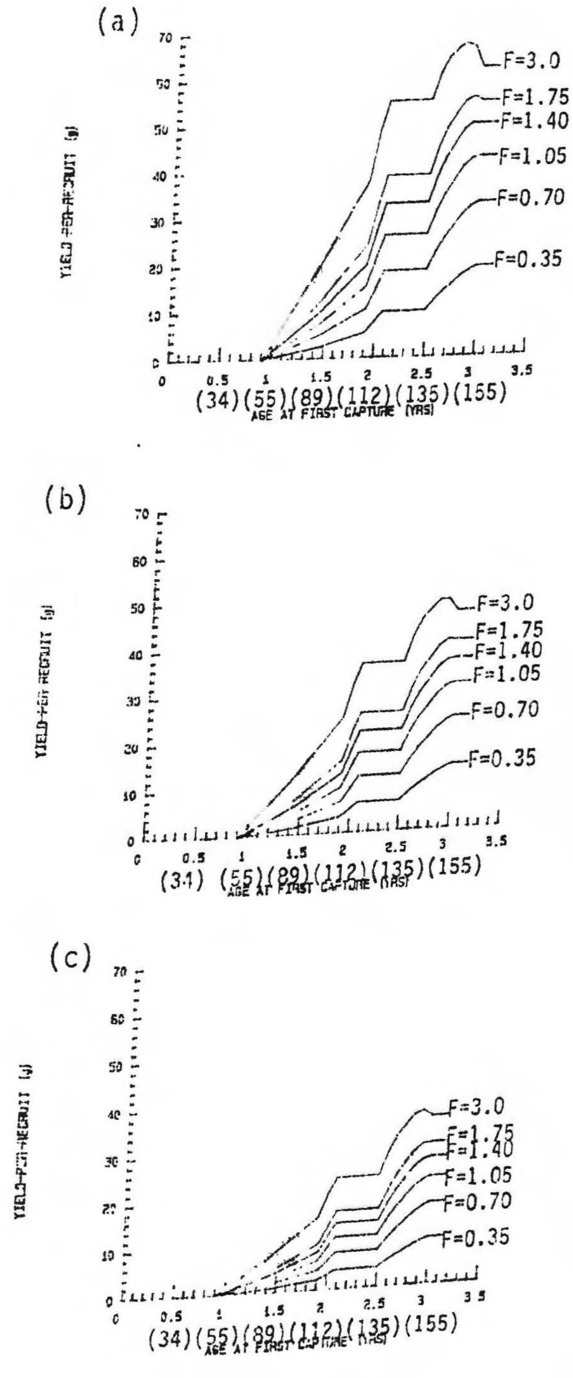

(a)
F=3.0
F=1.75
F=1.40
F=1.05
F=0.70
F=0.35
YIELD-PER-RECRUIT (g)
(34) (55) (89) (112) (135) (155)
AGE AT FIRST CAPTURE (YRS)
(b)
F=3.0
F=1.75
F=1.40
F=1.05
F=0.70
F=0.35
(34) (55) (89) (112) (135) (155)
AGE AT FIRST CAPTURE (YRS)
(c)
F=3.0
F=1.75
F=1.40
F=1.05
F=0.70
F=0.35
(34) (55) (89) (112) (135) (155)
AGE AT FIRST CAPTURE (YRS)

Figure 2.24. Yield-per-recruit as a function of age at first capture with constant fishing rates for female blue crabs with varying natural mortality rates: (a)M=0.30, (b)M=0.50, (c)M=0.70. (Numbers in parentheses on x-axis are size-at-age in mm).

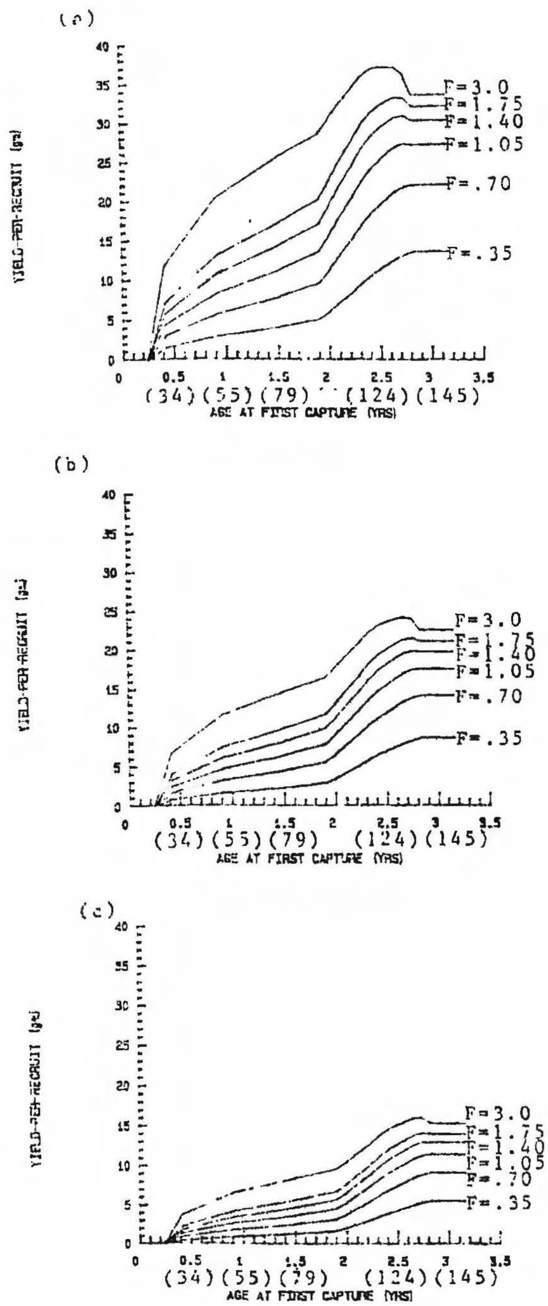
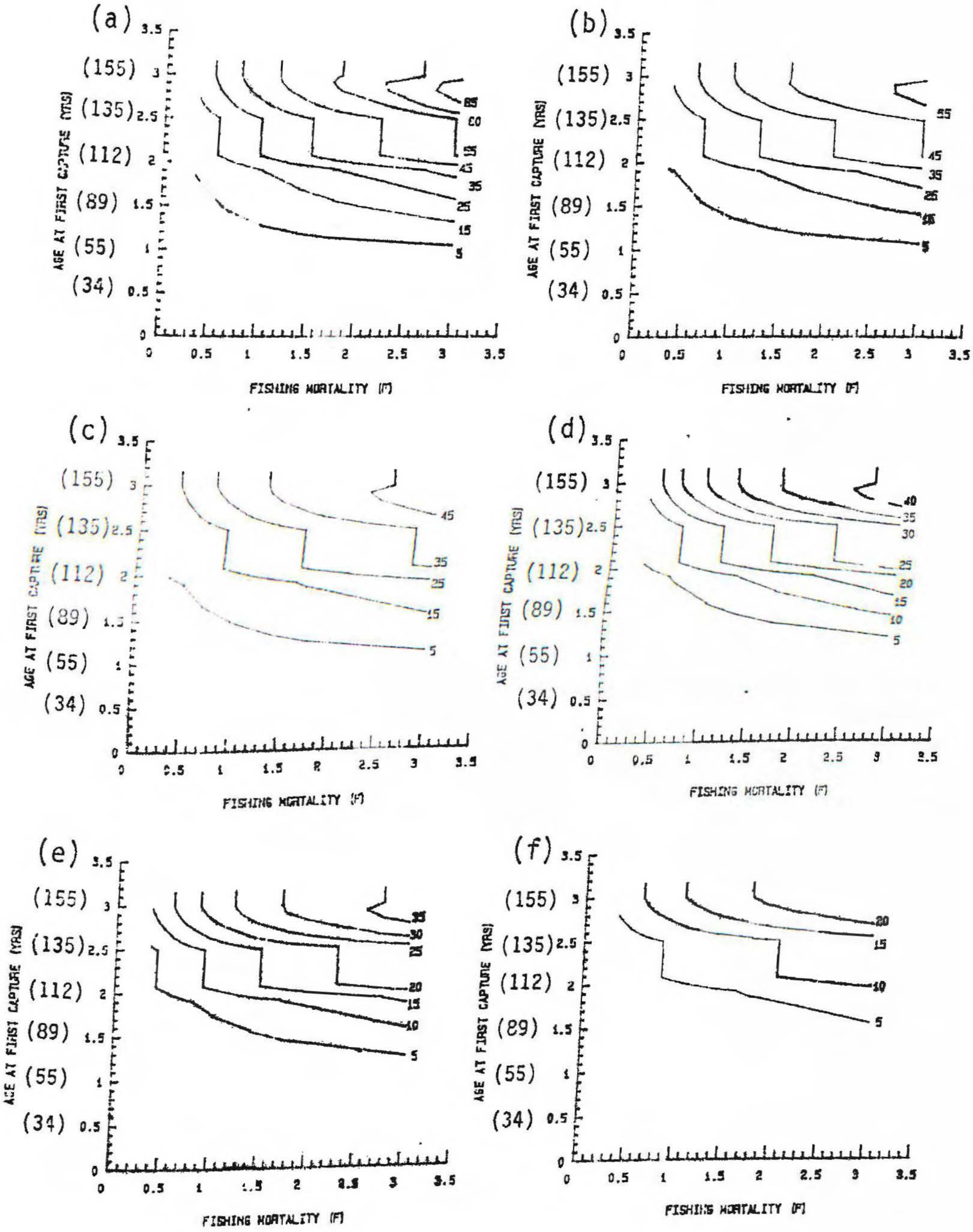

(a)
YIELD-PER-RECRUIT (g)
F=3.0
F=1.75
F=1.40
F=1.05
F=.70
F=.35
0 0.5 1 1.5 2 2.5 3 3.5
(34) (55) (79) (124) (145)
AGE AT FIRST CAPTURE (YRS)
(b)
YIELD-PER-RECRUIT (g)
F=3.0
F=1.75
F=1.40
F=1.05
F=.70
F=.35
0 0.5 1 1.5 2 2.5 3 3.5
(34) (55) (79) (124) (145)
AGE AT FIRST CAPTURE (YRS)
(c)
YIELD-PER-RECRUIT (g)
F=3.0
F=1.75
F=1.40
F=1.05
F=.70
F=.35
0 0.5 1 1.5 2 2.5 3 3.5
(34) (55) (79) (124) (145)
AGE AT FIRST CAPTURE (YRS)

Figure 2.25. Yield contour diagram for male Chesapeake Bay blue crabs. Contours are yield (grams) per crab, computed by the (arithmetic) Ricker method with varying natural mortality rates: (a)M=0.3, (b)M=0.4, (c)M=0.5 (d)M=0.6, (e)M=0.7, (f)M=1.0. (Numbers in parentheses on y-axis are size-at-age in mm).



(a)
(b)
(c)
(d)
(e)
(f)
AGE AT FIRST CAPTURE (YRS)
(155)
(135)
(112)
(89)
(55)
(34)
0
0.5
1
1.5
2
2.5
3
3.5
FISHING MORTALITY (F)
5
15
25
35
45
55
10
20
30
40

Figure 2.26. Yield contour diagram for female Chesapeake Bay blue crabs. Contours are yield (grams) per crab, computed by the (arithmetic) Ricker method with varying natural mortality rates: (a)M=0.3, (b)M=0.4, (c)M=0.5, (d)M=0.6, (e)M=0.7, (f)M=1.0. (Numbers in parentheses on y-axis are size-at-age in mm).

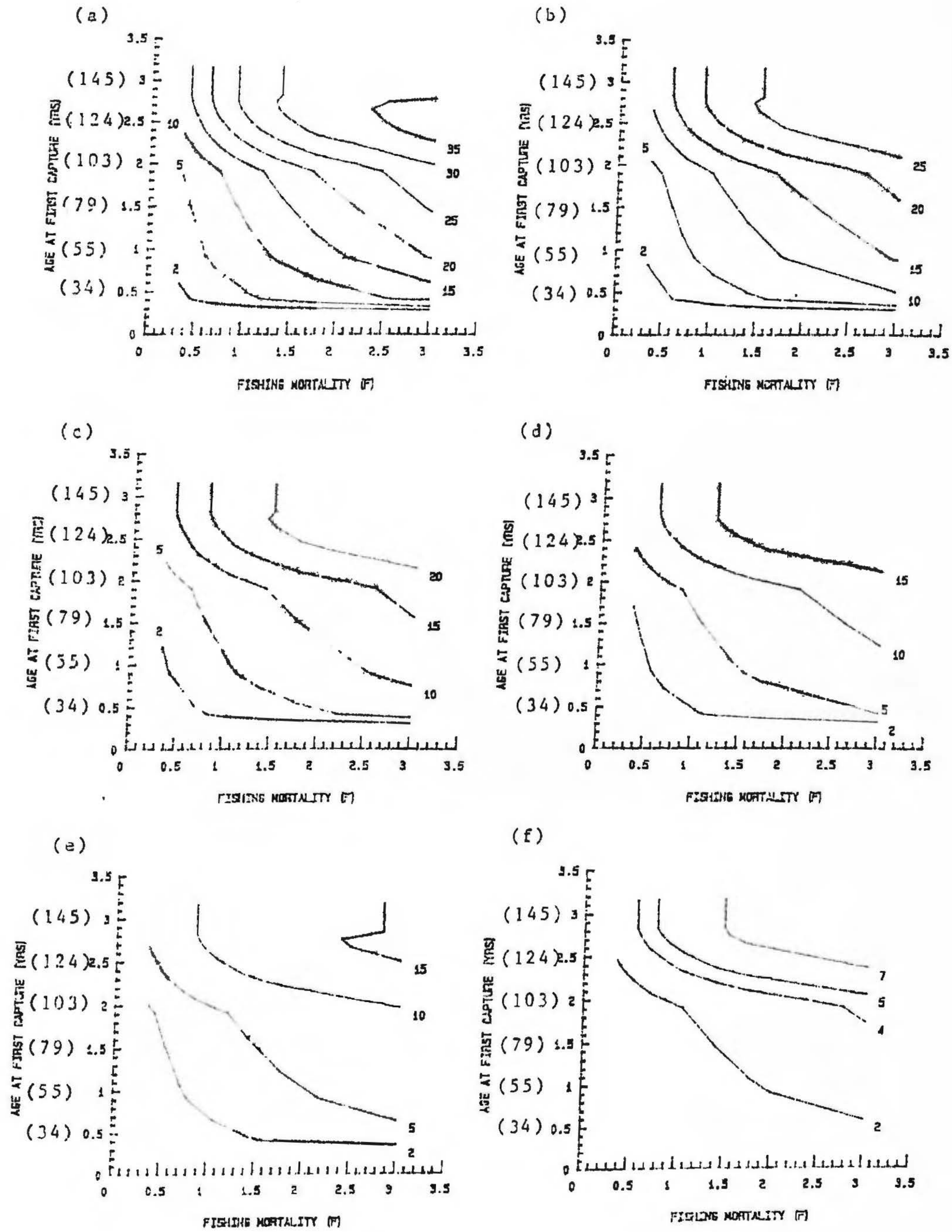

(a)
35
30
25
20
15
10
5
2
(b)
25
20
15
10
5
2
(c)
20
15
10
5
2
(d)
15
10
5
2
(e)
15
10
5
2
(f)
7
5
4
2
(145)
(124)
(103)
(79)
(55)
(34)
AGE AT FIRST CAPTURE (YRS)
FISHING MORTALITY (F)
0
0.5
1
1.5
2
2.5
3
3.5

Figure 2.27. Connected scatterplot of total combined Maryland and Virginia (hard and soft) crab catch (stock) versus the Smith Island scrape fishery recruitment index (lagged 2 years). (Years in parentheses are recruitment year).

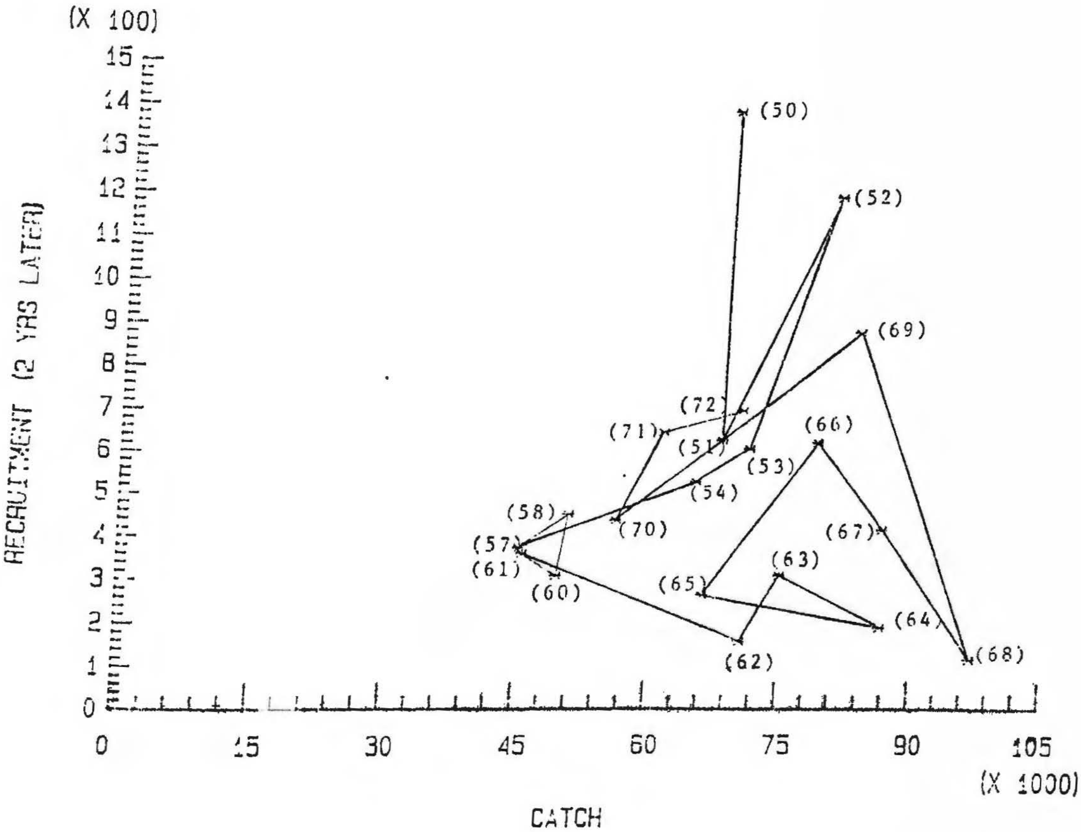

(X 100)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RECRUITMENT (2 YRS LATER)
(50)
(52)
(69)
(72)
(71)
(51)
(66)
(53)
(54)
(58)
(70)
(67)
(57)
(63)
(61)
(60)
(65)
(64)
(62)
(68)
0
15
30
45
60
75
90
105
(X 1000)
CATCH

Figure 2.28. Total combined Maryland and Virginia (hard and soft) crab catch (stock) and Smith Island scrape fishery recruitment index (lagged 2 years) over time. (Note: recruitment index and stock are on different scales).


(X 10000)
TOTAL CATCH
RECR. INDEX
1940
1945
1950
1955
1960
1965
1970
YEAR
RECR. INDEX AND TOTAL CATCH (LBS)

Figure 2.29. Catch curves for male blue crabs captured in the commercial pot fishery sampling in the early (5/23-7/09) and late (7/10-8/12) parts of the season.

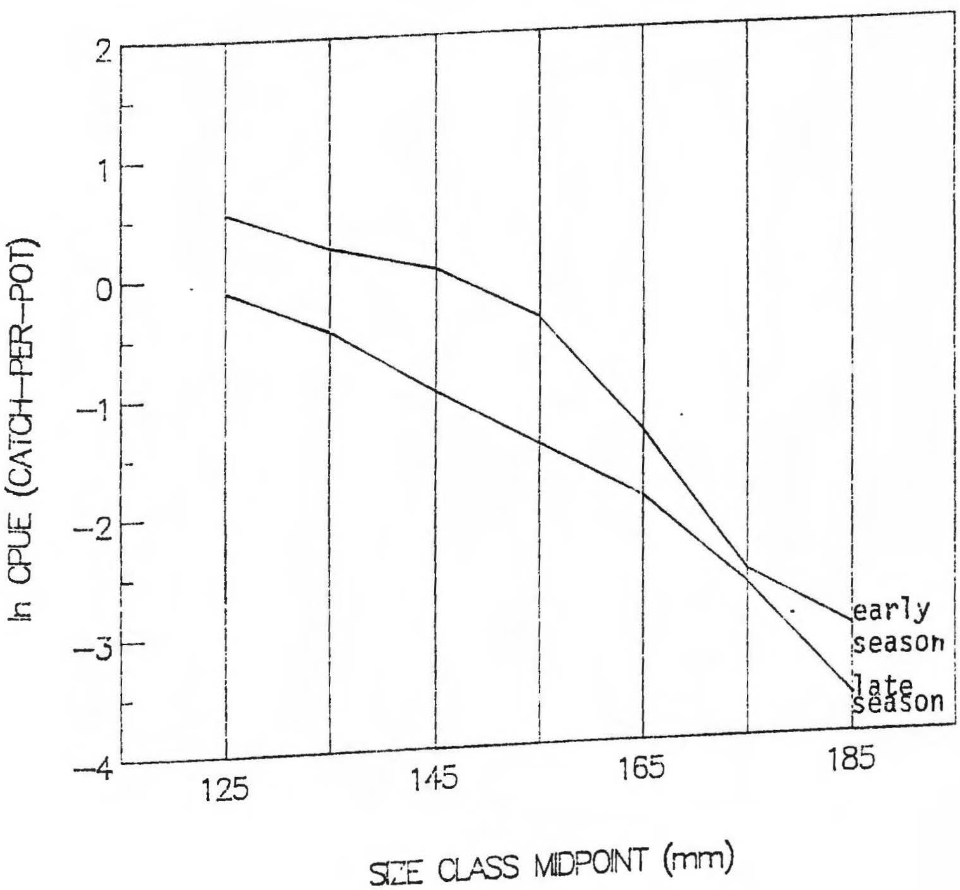
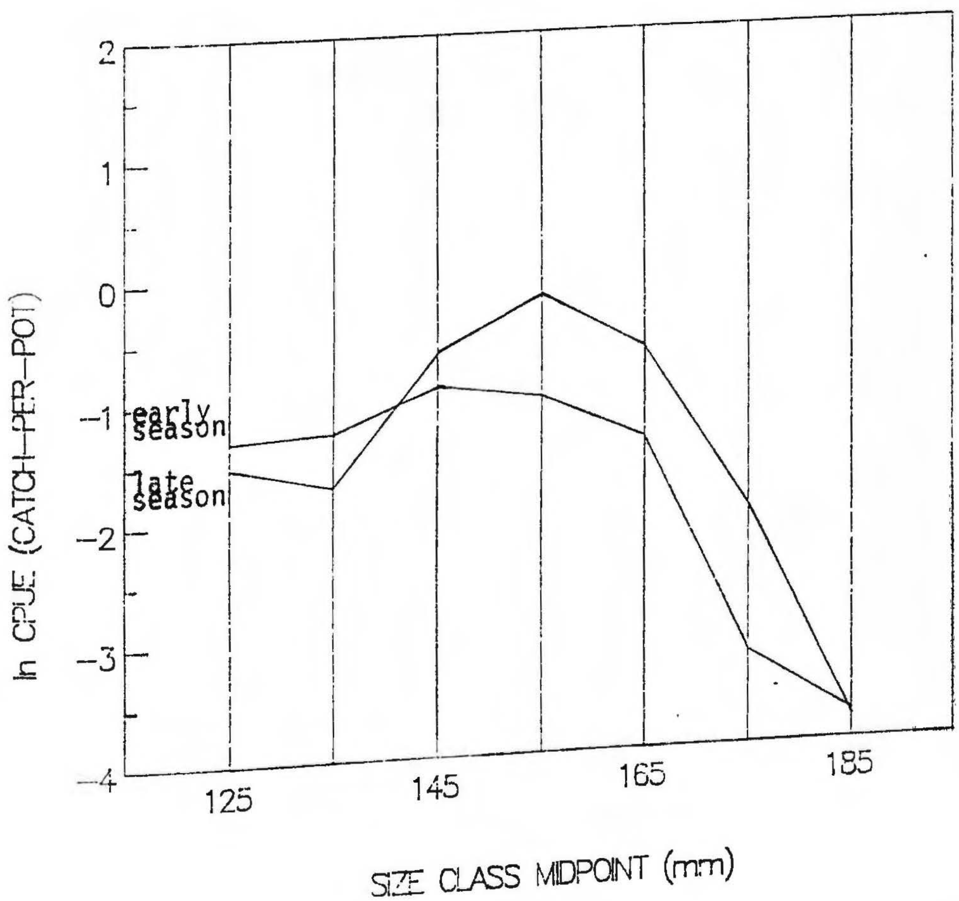
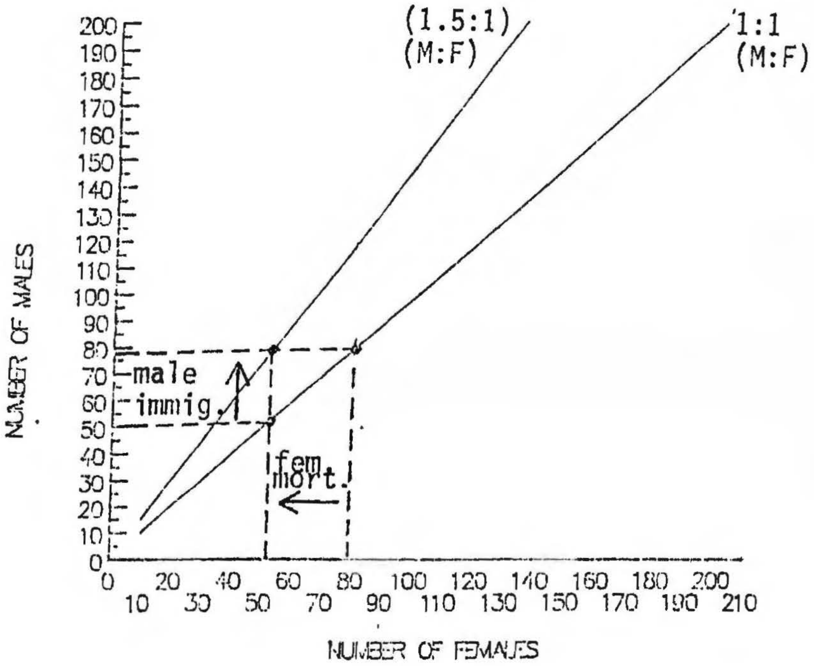

2
1
0
−1
−2
−3
−4
ln CPUE (CATCH-PER-POT)
125
145
165
185
SIZE CLASS MIDPOINT (mm)
early season
late season

Figure 2.30. Catch curves for female blue crabs captured in the commercial pot fishery sampling in the early (5/23-7/09) and late (7/10-8/12) parts of the season.



2
1
0
-1
-2
-3
-4
early
season
late
season
ln CPUE (CATCH-PER-POT)
125
145
165
185
SIZE CLASS MIDPOINT (mm)

Figure 3.1. Model of causes of deviation from 1:1 sex ratio in blue crabs.



(1.5:1)
(M:F)
1:1
(M:F)
male
immig.
fem.
mort.
NUMBER OF MALES
NUMBER OF FEMALES

Figure 3.2. List of questions addressed at the September, 1988 blue crab stock assessment workshop.

(1) Can the blue crab population in the Chesapeake Bay be overfished?

(2) What is the most current understanding of the stock/recruitment relationship and the varying environmental conditions that affect the relationship?

(3) Will harvesting crabs (males or females) affect the number of future crabs?

(4) Do low numbers of crabs (males or females) contribute to poor spawning success and ultimately a smaller stock size in succeeding years?

(5) What percentage of females are successfully impregnated during their lifetime?

(6) How does the harvesting of peelers and soft crabs affect the number of hard crabs in following years?

(7) Will raising the minimum size limit of peelers have a positive effect on future landings of hard crabs?

(8) Do pollutants affect growth rates, reproduction, or mortality?

(9) Is one life stage more vulnerable to pollutants than another?

(10) How would including mature females in the 5 inch minimum size limit impact the resource and the fishery?

(11) Would prohibiting a winter dredge fishery have a measurable beneficial or detrimental effect on the resource and the fishery?

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